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Mars Equipment Transport System

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Delta Connector
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Secondary Connector
Primary Connector
Secondary Connector
Primary Leg
Delta Leg
Apex Leg
Base Leg
Delta Pulley Connector
Base Pulley Connector

III. INTRODUCTION

IIIA. Background and Justification for Transport System

Mechanical Engineering Senior Design Project I (ME4182) is a part of the NASA / University Advanced Design Program. Under this program, NASA allocates money and resources to students to be used in design work for a specified topic. The current topic is the exploration and colonization of Mars. NASA is interested in determining the feasibility of living on Mars. The specific area in which we are to work is the transportation of the modules in which astronauts will live while on Mars. NASA is concerned about the weight of the module transferring system, as the shipping cost to Mars is quite expensive. NASA has specified that the weight of the system is to be minimized in order to reduce the shipping costs.

IIIB. Problem Statement:

The cost per unit weight of transporting materials to Mars is high. Accordingly, the equipment used to transport and assemble the Mars colony modules should be multifunctional and of minimal mass. By maximizing mechanical advantages, these transport systems will allow for the movement of heavy objects while necessitating minimal force. Therefore, we shall employ the techniques of riggers and roustabouts in the design of the system capable of transporting the Mars colony modules.

IIIC. Constraints:

Geophysical Constraints [2], [5]

- The gravity on Mars is 38% of the gravity on Earth.
- Wind velocities on Mars range up to 300 mph.
- Mars surface pressure ranges from 5×10^{-3} to 3×10^{-2} atm.
- Surface temperatures on Mars range from -100° F to 30° F.

Mechanical Constraints:

- The system must be operable by the Enabler.

IIID. Goals of Transport System:

Performance Objectives

- System should be able to lift and transport objects of maximal mass, 32 metric tons, and dimensions x, y, and z.
- System should be capable of performing several different modes of transport.

Evaluation Criteria

- System should be of minimal mass.
- System should be easy to operate and setup.
- System should be comprised of a minimal number of moving parts.
- System must be capable of transporting a 120,000 N (weight on Mars), 5 meter diameter, 14 meter long module

IV. SOLUTION SUMMARY

IVA. System Description

The METS design is essentially comprised of two three-legged towers which are connected by a transport line on which the module can be transported. Each tower is comprised of modular tubing and female connectors made of a graphite/epoxy composite. To stabilize the towers during the movement of the module, an anchor line is attached to each connector on the tower legs. Depending upon the local soil conditions, the number and type of the anchors will change. To protect the tower legs against outward buckling, support lines are attached at each primary connector and crossed to the adjacent tower line. These lines are simply attached by hooking onto the connectors so they can easily be moved depending upon the intended direction of the module. The transport line is tensed through the use of the winch installed on the Enabler. Once tensed, the transport line is anchored into the ground. As the Enabler reels in the transport line the module is raised. The module is connected to the transport line with a braking swivel shackle. With the assistance of the Enabler, the module can be moved to any point along the transport line between the two towers. The module can be lowered anywhere between the towers simply by using the winch to slowly release the transport line. If the module needs to be moved a longer distance than allowed with the transport line, the tower farthest from the desired location is de-anchored and moved with the help of the Enabler. Once the relocated tower is setup and anchored again, the transport of the module can continue.

Assembly

1. Remove METS equipment from transport canister
2. Attach apex legs to apex connector - the connector is threaded and requires 6 full rotations of each leg for attachment
3. Slide the two apex pulley connectors onto two pairs of the apex legs
4. Attach a delta connector to each apex leg-each connector is threaded and requires 6 full rotations of each leg for attachment
5. Attach anchor and support lines to all three base connectors
6. Attach the two feed lines the two apex pulleys
7. For each apex connector attached above, slide the two corresponding delta legs through the connector
8. Attach delta poles to delta connectors - each connector is threaded and requires 6 full rotations of each leg for attachment
9. Lay the assembly on the Mars surface with apex down
10. Attach three primary legs, support lines, and anchor lines to the three delta connectors
11. Position system so 2 legs lie on ground
12. Attach female connectors, support lines (crossing support lines), and anchor lines to first legs - each connector is threaded and requires 6 full rotations of each leg for attachment
13. Attach 1 primary leg each to the 2 legs on the ground
14. Attach primary connectors, support lines and anchor lines to legs on ground-each connector is threaded and requires 6 full rotations of each leg for attachment
15. Attach primary legs to each primary connector
16. Attach primary connectors, support lines and anchor lines to legs on ground
17. Attach fourth primary leg to each primary connector
18. Rotate the system and repeat the process of attaching the primary legs, anchor lines, and support lines (crossing support lines) for the third tower leg
19. Slide the two base pulley connectors onto two primary legs
20. Attach a base connector the two selected primary legs
21. Slide two base legs through the two base pulley connectors and attach the two base legs to each of the selected primary legs with the base connectors-each connector is threaded and requires 6 full rotations of each leg for attachment
22. Attach secondary connectors to each of the base legs

23. Attach a secondary connector to a third base leg
24. Attach the remaining two base legs using the secondary connectors-each connector is threaded and requires 6 full rotations of each leg for attachment
25. Rotate the assembly
26. Attach a base connector each to the other primary leg on the ground
27. Slide a base poles through the base pulley connector attach it to the primary leg with the base connectors - each connector is threaded and requires 6 full rotations of the leg for attachment
28. Attach a base connector to the primary leg without the base pulley connector
29. Attach secondary connectors to the two base legs
30. Attach secondary to both base legs and attach a secondary connector to a new base leg
31. Attach the four base legs together using the secondary connectors-each connector is threaded and requires 6 full rotations of each leg for attachment
32. Rotate the system
33. Attach two base legs to each of the primary legs on the ground
34. Attach secondary connectors to each of the base legs
35. Attach a secondary connector to both ends of the base legs
36. Attach a secondary connector to a new base leg
37. Attach the four base legs using the secondary connectors-each connector is threaded and requires 6 full rotations of each leg for attachment
38. Move assembly to desired location
39. Recheck assembly to ensure that all anchor lines, support lines, transport lines and feed lines are properly attached
40. Repeat for second tower

Setting up Towers

1. Anchor two legs to ground
2. Pull on third tower leg with Enabler and raise to standing position
3. Check local soil conditions for required number of bridle anchors
4. Tense each anchor line with winch on Enabler and anchor to ground with required number of bridle anchors
5. Tense and anchor transport line with winch and anchor to ground with required number of bridle anchors
6. Raise and anchor the second tower in the same manner

IVB. OPERATION DESCRIPTION

Raising the Module

The towers will be assembled and moved into their desired positions. Before the towers are raised, the transport line must be threaded through the pulleys at the both the starting and the finishing tower. The tail end of the transport line should be anchored at the finishing, or second tower. The lead end of the transport line should then be fed through the anchors at the starting, or first tower. The anchors at this location will not be secured until the module has been lifted and the transport line has achieved the necessary tension.

The module should be placed underneath the first tower. The transport roller system will then be attached to the top of the module. See Figure 1 below. The lead end of the transport line will be fed into the winch on the Enabler. When the winch is activated, the slack in the line will start to decrease, and the line will begin to move upwards. The line will come up underneath the transport rollers and begin to raise the module. When the module has reached the top of the tower, the winch will be deactivated and the transport brake will be applied. The brake and the winch can both be controlled at a remote location. The Enabler will then use its arm to anchor the lead end of the transport line. The line can then be removed from the winch.

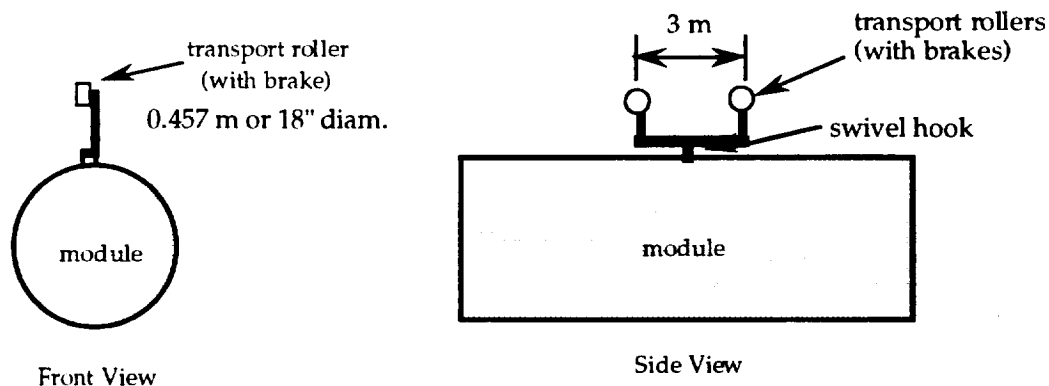


Figure 1
Transport Roller

Horizontal Motion

The acceleration, deceleration, and speed of the module will be completely controlled by the Enabler and the pulley braking system. It is important that the Enabler resist the module's tendency to accelerate too quickly down the line. There will be guiding handles on the bottom of the module, towards the front and rear, that the arm of the Enabler can clasp. The Enabler also remotely controls the braking system on the transport rollers. When transporting horizontally, the transport brake will be released, and the Enabler, by claspings a guide handle, will slowly guide the module out from under the first tower across the transport line to the second tower. The roller transport system setup allows the module to be rotated in any direction. This capability will be used in guiding and lowering the module.

Motion Past the Second Tower

When the module reaches the second tower, it will be lowered back down to the ground. To lower the module, the transport brake should first be applied to stabilize the module. The lead end of the transport line at the first tower will be fed back into the winch on the Enabler, and the anchors will be removed. The line will then be let out while simultaneously releasing the transport brake. This will allow the module to be lowered to the ground. This same process can be followed if the module must be lowered in between towers, also.

At this point, the module has either reached it's destination, or needs to go further. If the second case is true, the first tower will be moved past the second tower, and the transport process will be repeated. This will continue until the module arrives at it's desired location. To move the first tower, the anchors will first be removed. The arm of the Enabler should be able to clasp one of the primary tower legs, pick the tower up, and move the tower to its next location. If the Enabler encounters stability problems, it will pull the tower over and tow it to the desired position to set up again.

To change the direction from which the module leaves the tower, two of the three legs has a pulley system with feed lines. The feed lines will guide the horizontal transport line through the side pulleys. This allows the horizontal line to be setup in any direction. See Figures 2a through 2c below. Note that the size of the pulleys

in these Figures have been exaggerated for clarity. If less than the full one hundred meters must be traveled, the towers can be placed closer together. The only alteration to the system would be that the anchors on the lead end of the transport line would be secured closer in.

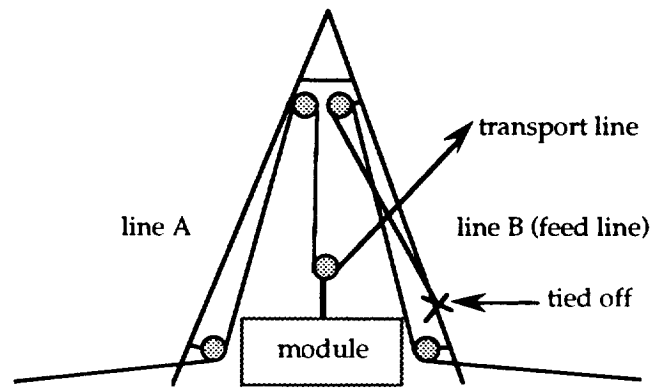


Figure 2a
Feed Line Operation

(a) The module has been transported to the second tower and lowered to the ground. Line A is anchored and goes towards the first tower. The feed line B is not used at this point.

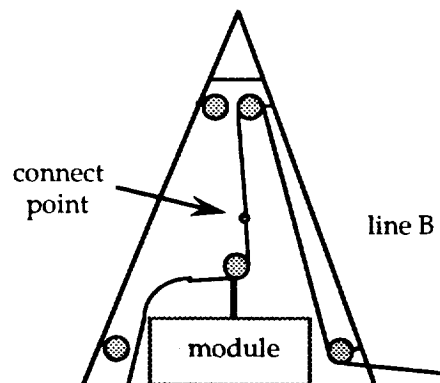


Figure 2b
Feed Line Operation

(b) The anchors for Line A are removed, the transport line is fed through the pulleys, and the lead end is left free. The feed line B is untied from the tower and connected to the tail end of the transport line.

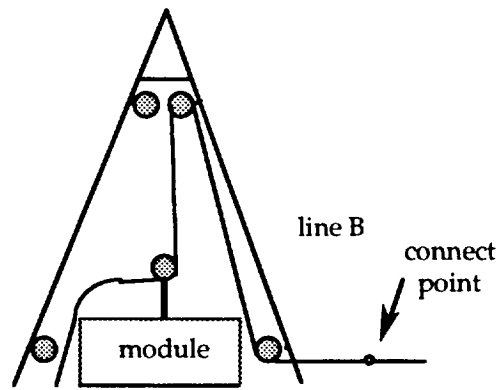


Figure 2c
Feed Line Operation

(c) The line is lead through the pulleys until the connect point has passed the lower pulley. At that point, the transport line has been fed through the pulley system and can be disconnected from the feed line. The tail end of the transport will then be anchored down. The lead end will be guided through the system on the other tower before it is raised.

IVC. Material Selection

Tower Material [1], [9]

The constraints on the material selection for the tower were to maximize strength and at the same time minimize the weight. Composite materials optimize these qualities. The atmosphere of Mars limits the choices of composites. Because of the high radiation, all plastics were eliminated. The constant barrage of dust in the atmosphere removed any composite that did not have a good resistance to abrasion. Research was done into recent NASA projects concerning Space Station *Freedom*. It was found that NASA uses graphite/epoxy composites for their truss work. The graphite fiber reinforced epoxy resin matrix fit the initial guidelines for the tower material. Data for the analysis was obtained from Reference 9. Graphite reinforcement provides the necessary strength, and has superior strength qualities when compared to metals. An epoxy resin matrix is light weight, and has good abrasion resistance. Together, they make a composite that meets the needs for the equipment transport system on Mars. The graphite/epoxy composite has a compressive strength of roughly 1200 MPa. Since the major forces experienced by the tower would be compressive forces, this strength was used in the calculations. The density of the composite is roughly 1500 kg/m³, making it one of the more light weight composites.

Information contained in Appendix C (in the Group notebook) was used for comparisons to other materials. Figure 13 of this paper further verifies that the graphite/epoxy combination is best to optimize high strength with low weight. In this figure, the shaded areas denote potential matrices, while the unshaded areas denote potential reinforcements. Epoxy is found under the polymer classification. The polymers have the lightest weight, and epoxy can be seen to be the strongest of the polymers. Graphite falls into the carbon category. It is one of the stronger choices for reinforcements.

The graphite/epoxy combination is clearly one of the best composites for the tower system. Its previous use by NASA at Space Station *Freedom* is also a definite advantage in that engineers and astronauts are already familiar with the material, its properties, and its possible uses. Resources may be available through NASA's past research and development of the composite. This would reduce the cost, and

increase the efficiency, of the Mars system.

Transport Rope Material [3]

The kevlar aramid fibers exhibit properties of low stretch, high tensile strength, good performance over a large temperature range, excellent fatigue resistance, low creep, and low density. The tensile strength of Kevlar 49 is approximately 2.75 GPa. As temperature increases, the tensile strength slightly decreases. For example, at -45.6°C Kevlar 49 has a tensile strength of 2.50 GPa, while at 23.9°C the tensile strength is 2.40 GPa. This data shows that the kevlar rope will perform adequately in the temperature range on Mars.

Fatigue data for kevlar shows that at 10^7 cycles Kevlar 49 can withstand 1.7 times the stress of steel and 3.4 times the stress of nylon. Cyclic fatigue caused by continual tensile loading and unloading also has little or no effect on kevlar fibers. Further tests show that creep is usually less than 0.2 percent elongation. Kevlar also has good environmental stability, meaning that its chemical resistance to common solvents, oils, greases and water is good. The only negative aspect of Kevlar is concerns with self-abrasion. This is where individual fibers abrade one another and therefore degrade the material. The excess dust on Mars could aggravate the problem. It may be necessary to apply a protective coating to the kevlar line for this reason.

The advantages of kevlar far outweigh its disadvantage. The density of kevlar is also very low, 1440 kg/m^3 . Its superior strength, low weight, and fatigue resistance make kevlar an ideal choice for the transport and lines for the METS design.

IVD. Validation of Design [8], [9]

Will the members buckle?

P_{cr} = critical load

n = end constant = 4

E = modulus of elasticity = $125 \cdot 10^9$ Pa

S_y = compression yield strength = $1200 \cdot 10^6$ Pa

l = length of member = 5 m

r = radius of member = 0.120 m

$$\therefore P_{cr} = \frac{n \cdot \pi^2 \cdot E \cdot A}{\left(\frac{l}{r}\right)^2} = 5,133,000 \text{ N} > 120,000 \text{ so members will not buckle}$$

If the tower legs are considered as one continuous member, the buckling will occur under the following load:

l = length of tower leg = 20 m

$$\therefore P_{cr} = \frac{n \cdot \pi^2 \cdot E \cdot A}{\left(\frac{l}{r}\right)^2} = 320,841 \text{ N} > 120,000 \text{ so members will not buckle}$$

Therefore the members will not buckle under the load of the module.

Will the member buckle or yield first?

If $\frac{P_{cr}}{A_c} < S_y$ where A_c is the cross section of member and S_y is the yield strength of the material then the member will buckle before it will yield.

$$P_{cr} = 320,841 \text{ N}$$

$$A_c = \frac{\pi}{4} \cdot (D_o^2 - D_i^2) = \frac{\pi}{4} \cdot (0.12^2 - 0.11^2) = 1.8 \cdot 10^{-3} \text{ m}^2$$

$$S_y = 1200 \text{ MPa}$$

Since $\frac{P_{cr}}{A_c} = 1.8 \cdot 10^8$ the members will buckle before yielding.

What anchor line tension is required to prevent the tipping of the tower?

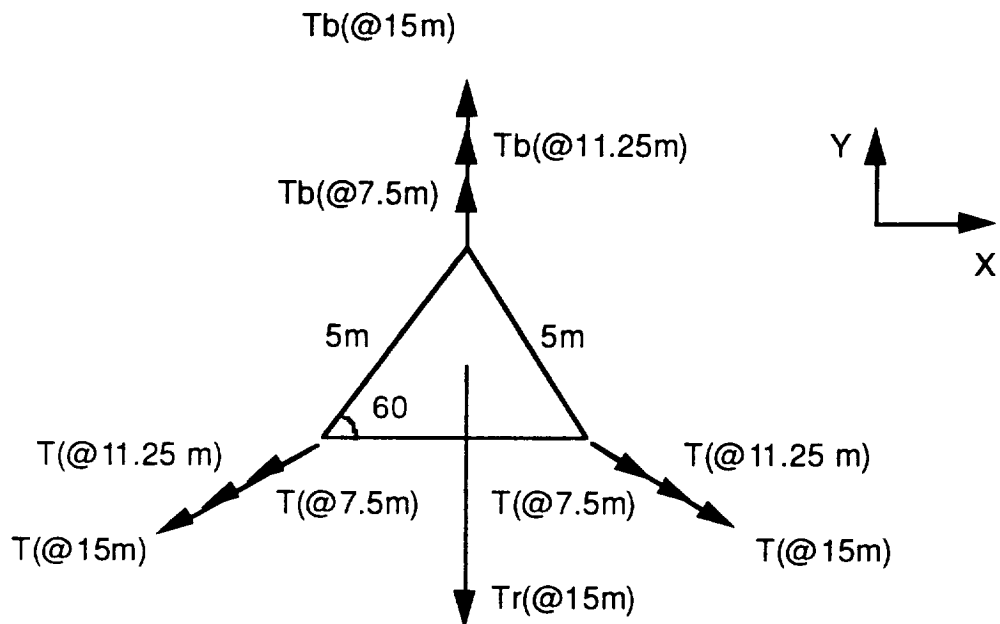


Figure 3
Anchor System for Tower
Top View

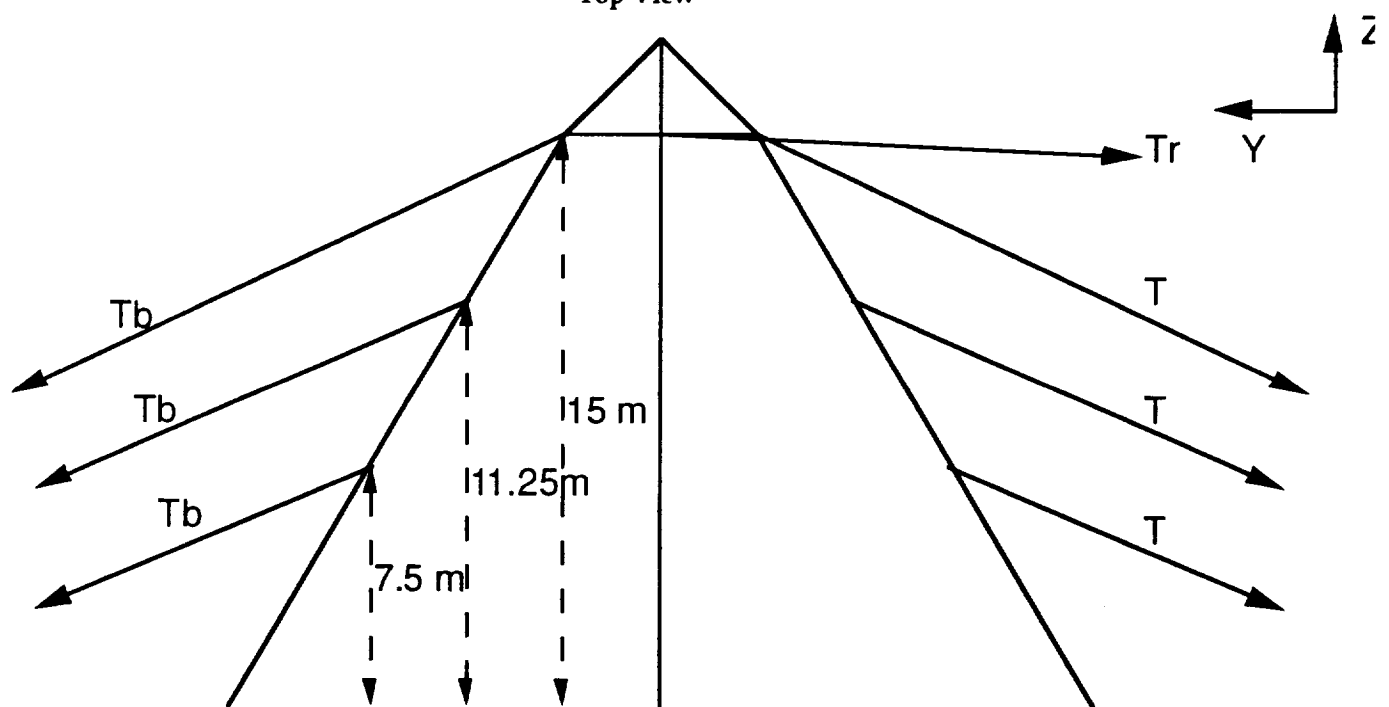


Figure 4
Anchor System
Side View

Given the above anchor design, shown in Figures 3 and 4, the required tension in the anchor lines was calculated as follows:

The following variables were used in the calculations:

- T_h : horizontal component of T
- T_v : vertical component of T
- T_{bh} : horizontal component of Tb
- T_{bv} : vertical component of Tb
- T_{rh} : horizontal tension in transport line
- T_{rv} : vertical tension in transport line
- F: force resulting from impact of module to tower

$$\begin{aligned} \sum M_{\text{ground at back leg}} = & T_{rh} \cdot 15 \hat{i} - T_{bh} \cdot (15 + 11.25 + 7.5) \hat{i} - T_{bv} \cdot (10 + 7.5 + 5) \hat{i} \\ & + T_h \cdot \sin(60^\circ) \cdot (15 + 11.25 + 7.5) \hat{i} - F \cdot 15 \hat{i} - T_{rv} \cdot 12.5 \hat{i} = 0 \end{aligned} \quad [\text{Eq. 1}]$$

Tension Required when Module is leaving tower:

For this scenario, the following assumptions can be made:

- $T = 0$
- $F = 0$
- $T_{rh} = T_r$, ($T_{rv} = 0$), worst case scenario
- $T_r = \text{weight of module} = 120 \text{ kN}$

Therefore, equation 1 can be reduced to the following:

$$\sum M_{\text{ground at back leg}} = T_r \cdot 15 \hat{i} - T_{bh} \cdot (15 + 11.25 + 7.5) \hat{i} - T_{bv} \cdot (8.66 + 6.5 + 4.33) \hat{i} = 0$$

$$\sum M_{\text{ground at back leg}} = T_r \cdot 15 \hat{i} - T_{bh} \cdot (33.75) \hat{i} - T_{bv} \cdot (19.5) \hat{i} = 0$$

$$\sum M_{\text{ground at back leg}} = T_r \cdot 15 \hat{i} - T_b \cdot \cos(60^\circ) \cdot (33.75) \hat{i} - T_b \cdot \sin(60^\circ) \cdot (19.5) \hat{i} = 0$$

$$\therefore T_b \approx 55,000 \text{ N} = T \text{ (all tensions are equal)}$$

Can the delta bar with block support the module?

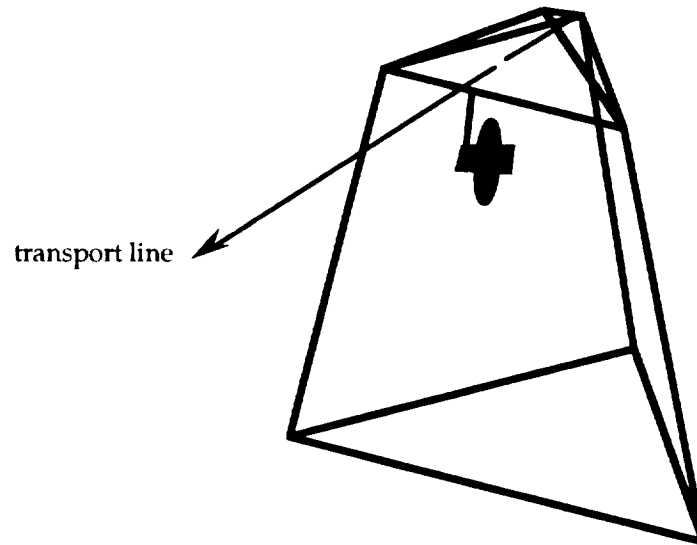


Figure 5
Delta Bar with Block

The amount of force a pulley block must handle depends on the angle of line deflection around the pulley. The amount of force in the line is multiplied by an angle factor. A table of angle factors is provided below:

Angle Factor Multipliers			
Angle	Factor	Angle	Factor
0°	2.00	100°	1.29
10°	1.99	110°	1.15
20°	1.97	120°	1.00
30°	1.93	130°	.84
40°	1.87	135°	.78
45°	1.84	140°	.68
50°	1.81	150°	.52
60°	1.73	160°	.35
70°	1.64	170°	.17
80°	1.53	180°	.00
90°	1.41	—	—

Figure 6
Angle Factors

The maximum force on the pulleys is calculated below:

$$F_{\max} = \text{weight} \cdot 1.41 = 169,200 \text{ N}$$

The transverse tensile strength of the graphite epoxy used for the delta bar is:

$$\sigma_y = 45 \text{ MPa}$$

The maximum allowed force is:

$$F_{\text{max allowed}} = \sigma \cdot A = \sigma \cdot \frac{\pi \cdot D^2}{4}$$

$$D = 0.12 \text{ m}$$

$$\therefore F_{\text{max allowed}} = 508,938 \text{ N}$$

Therefore, the delta bar can support the entire module with a safety factor of 4.2.

Can the pulley connectors support the load on the base blocks?

The load on the base pulley connectors is 120,000 N, the weight of the module. The outer and inner diameters of the tubing are 14cm and 12cm, respectively. The cross sectional area is determined below:

$$A_c = \frac{\pi \cdot OD^2}{4} - \frac{\pi \cdot ID^2}{4} = \frac{\pi \cdot (0.14)^2}{4} - \frac{\pi \cdot (0.12)^2}{4} = 4.08 \cdot 10^{-3} \text{ m}^2$$

The properties for graphite/epoxy composite are as follows: [9]

$$\sigma_{\text{long, tensile}} = 1300 \text{ MPa}$$

$$\sigma_{\text{long, compressive}} = 1200 \text{ MPa}$$

Therefore the maximum force can be calculated as follows:

$$F_{\text{mx}} = \sigma_{\text{long, compressive}} \cdot A_c = 4,900,000 \text{ N}$$

The base pulley connector, assuming one arm sees the entire load, can withstand the load on the block by a safety factor of 40.

Can the pulley connectors support the load on the apex blocks?

The load on the apex pulley block is 240,000 N. Therefore, assuming that each arm of the pulley connector needs to withstand the total load on the block, the maximum force and safety factor were calculated as shown:

$$A_c = \frac{\pi \cdot OD^2}{4} - \frac{\pi \cdot ID^2}{4} = \frac{\pi \cdot (0.14)^2}{4} - \frac{\pi \cdot (0.12)^2}{4} = 4.08 \cdot 10^{-3} \text{ m}^2$$

The properties for graphite/epoxy composite are as follows: [9]

$$\sigma_{\text{long,tensile}} = 1300 \text{ MPa}$$

$$\sigma_{\text{long,compressive}} = 1200 \text{ MPa}$$

$$F_{mx} = \sigma_{\text{long,compressive}} \cdot A_c = 4,900,000 \text{ N}$$

$$n = \text{safety factor} = 20$$

IVE. Future Multitasking Possibilities

The nature of the components of the Mars Equipment Transport System allows them to be utilized for numerous other applications on the planet. Since the tower system is modular, the poles, connectors, blocks, and rope could be assembled in numerous patterns and used in any project that uses the basic fundamentals of mechanical engineering. For example, NASA has plans to conduct mining development on Mars. The poles and the pulley system could be used in the construction and stabilization of the tunnels down into the surface of the planet, and later in the retrieval of material. The tower system could also be used for radio transmissions on the planet. The modular poles and connectors could provide scaffolding for construction and the pulley system could be used to raise and lower materials or machines. The tower poles could also be used for truss structures similar to that of Space Station *Freedom*.

The possibilities for the applications of poles, connectors, rope, and pulleys are endless. The high strength that is displayed by both the composite matrix poles and the kevlar rope make them valuable assets to have during the exploration of Mars.

IVF. Enabler Interfaces

Several specifications for Enabler abilities have been requested in the METS design as follows:

- Assembling of tower system
- Setting up tower
- Anchoring of towers
- Hoisting/lowering of module
- Controlling transport motion and direction of module
- Threading and removal of transport line
- Positioning support lines
- Removal of anchors
- Tipping of tower
- Picking up and moving tower
- Remote control operation of braking system

The most significant interfaces required by the METS design include the winch for hoisting/lowering the module and the hydraulic hammer for anchoring the tower. However, other systems for the winch and hammer may already be designated to be shipped to Mars. If so, the requirements for the Enabler may change.

IVG. Bill of Materials

QTY	PART NAME	DESCRIPTION	WEIGHT (kg)	TOTAL WT (kg)
2	TRANSPORT ROLLER	18" Diam., heavy steel	74.89	149.78
4	DELTA POLE BLOCK	18" Diam., heavy steel	74.89	299.56
4	BASE BLOCK	18" Diam., light steel	51.74	206.96
1	ENABLER WINCH	27,400 lb capacity	907.80	907.80
24	BASE LEGS	5 m long, 6 cm OD, 5 cm ID	6.48	155.52
24	PRIMARY LEGS	5 m long, 12 cm OD, 10 ID	25.92	622.08
6	DELTA LEGS	5 m long, 12 cm OD, 10 ID	84.82	508.92
6	APEX LEGS	2.87 m long, 12 cm OD, 10 cm ID	14.86	89.16
2	APEX CONNECTOR	see ACAD drawing	2.76	5.51
18	PRIMARY CONNECTOR	see ACAD drawing	1.77	31.81
18	SECONDARY CONNECTOR	see ACAD drawing	0.28	5.09
6	DELTA CONNECTOR	see ACAD drawing	2.94	17.64
6	BASE CONNECTOR	see ACAD drawing	0.80	4.79
4	APEX PULLEY CONNECTOR	0.30 long, 14 cm OD, 12 cm ID	2.75	11.00
8	BASE PULLEY CONNECTOR	0.30 long, 14 cm OD, 12 cm ID	6.39	51.12
1	TRANSPORT LINE	228 m long	166.36	166.36
4	FEED LINE	45 m long	32.83	131.32
6	ANCHOR LINE @ 15 m	25 m long	18.24	109.44
6	ANCHOR LINE @ 12.5 m	22.5 m long	16.42	98.52
6	ANCHOR LINE @ 7.5 m	17.5 m long	12.77	76.62
44	ANCHORS	1180 cm ³ , 2 per anchor line,	1.77	77.88
		4 per end of transport line		
SYSTEM WEIGHT			3727	

V. SUBSYSTEMS

VA. Pulley Connectors

In order to distribute the loading on the pulleys to different tower legs and alleviate stress on the connectors, pulley connectors are to be used to stabilize the base and apex blocks. The design of the pulley connectors for the base and apex blocks are similar and only differ by the angles between the three poles on which they are attached. The pulley connectors are molded of graphite/epoxy composite. Each connector consists of three arms 2 cm thick protruding from a yoke placed about the center of rotation of the pulley. The arms terminate in a connector that fits firmly around the base legs and primary leg. The pulley's locations must be planned before tower assembly occurs. The pulleys are design to be easily attached by their connectors to any leg during the assembly phase. However, their position may not be adjusted safely while the tower is in an upright and assembled condition.

VB. Pulley Systems

The recommended blocks for the METS design are made by McKissick Blocks. Information on pulley specifications and standards was obtained from Superior Rope and Sling, Inc. A diagram labeling the parts of a pulley was found in the NTIS database and is provided in the Appendix. The diameter of the line has been determined to be 1 in (2.54 cm). According to industry standards, the diameter of the sheave should be at least 15 times greater than the diameter of the line. This is to minimize the fatigue induced on the line while it is bent around the pulleys.

According to industry standards, the depth of the groove should be 1 to $1\frac{1}{2}$ times the line diameter. Anti-friction bearings are necessary due to the large forces the system will be handling.

Base Blocks

The calculation for the total load on the base blocks is as follows:

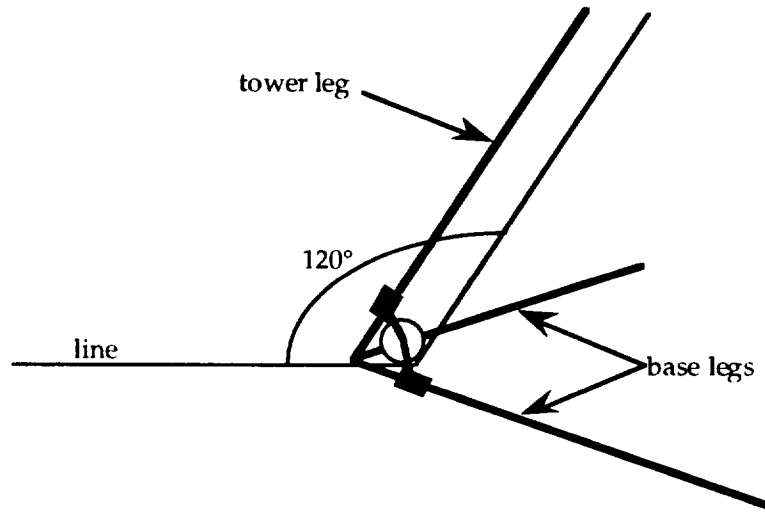


Figure 7
Base Pulley Connector

$$\text{Total load} = T \cdot (1.00)$$

If T is assumed to be the weight of the module, then

$$\text{Total load}_{\text{base block}} = 120,000 \text{ N}$$

A McKissick tail board block with a diameter of 18 in (45.72 cm), which is rated at 15 metric tons, will be used for the two base blocks. This yields a safety factor of 4 and a weight of 43.32 lbs (192.7 N).

Delta Pole Blocks

The maximum and minimum angles the line will bend around the sheave are 180° and 90° , respectively. The corresponding angle factors are 0 and 1.41 (refer to section IVC, figure 6). Therefore:

$$\text{Total load}_{\max} = \text{weight} \cdot 1.41 = 169,200 \text{ N}$$

Super Champion McKissick blocks will be used for the delta pole blocks. Some information about these blocks is provided below:

Rated load:	244,652 N (with a safety factor of 4)
Earth weight:	1651 lbs (278.9 N)
Sheave diameter:	18 in (45.72 cm)

Apex Blocks

Similar calculations were made for the Apex block. Since the load on the apex blocks is 240,000 N

Transport Roller

A swivel shackle will be used so that rotating the module is possible. The sheave diameter of the two pulleys for the transport roller will both 0.46 meters and the groove depth will be 0.3175 meters. The maximum force the pulley can handle is 196,000N, with a safety factor of 4.

VC. Tower Tubing Connectors

The sections of modular tubing to be employed must be able to be connected in a great variety of ways to allow for maximum multi-functionality. However, structural integrity cannot be sacrificed. A system for joining truss members in a low or micro-gravity environment has been and is being developed by NASA for use in the Earth Orbiting Space Station *Freedom*. These Connectors have been designed specifically so that either a robot articulated arm or a human astronaut in a space suit may fasten the trusses together.

In the present NASA node design, human completion of joint construction was measured at 38 seconds per node. These measurements were made in simulated micro-gravity (in buoyancy tanks), in parabolic trajectory simulated micro-gravity airplane flights, and finally in low Earth orbit during an E.V.A. during a Space Shuttle Flight. We therefore have designed our truss joints by utilizing the patented joint assembly mechanism already developed by NASA for use in space, with minor adjustments for increased structural rigidity. The METS trusses should be able to be joined with similar speed, accuracy, and increased integrity, while necessitating no further astronaut training with regard to truss assembly. The close relations that will exist between the Mars Transport truss assembly and the low Earth orbit truss assembly reflect a more modular system of space construction techniques that NASA has deemed necessary to increase efficiency, multi-functionality, and system performance, and maintenance.

This assortment allows for all possible anticipated configurations to be erected with no wasted parts. Additional connectors may be utilized if other tasks are determined that the METS components will be needed to perform. Possible additional connectors include:

- Planar- 120 degree Female-Female Connectors
- Three Dimensional 45 degree Female-Female Connectors
- Three Dimensional 60 degree Female-Female Connectors

VD. Anchors [4]

Soil Anchors

Manta Ray anchors will be used to secure the towers in sand. These anchors are used by the United States Department of Agriculture Forest Service and are made by Foresight Products, Inc. The Manta Ray anchor is ideal for use in loose, sandy soil.

To drive the anchor into the soil of Mars, a hydraulic, pneumatic or gas hammer is needed. It may be possible to use a sledge hammer, but this can only be determined on Mars. A driving rod is attached to the anchor by inserting it into the hole at the top of the anchor. The anchor is positioned so that the line, which is already attached, faces the direction of pull and is driven straight down to the desired depth (5 ft is the minimum). The driving rod is then removed by twisting and pulling it out of the anchor. A trench should be dug along the direction of pull so that the attachment cable tends to dig into the side of the installation hole and pulls the anchor toward undisturbed soil.

Each anchor line will most likely need to be secured by more than one anchor. This can only be determined by on-site experimentation. (This is necessary because the holding capacity of soil cannot be predicted within any acceptable accuracy.) To do this, a number of anchors are installed as described above. They are then stressed to failure by a measured force. The mean and standard deviation of these "pullout" forces are then calculated. This data and the known maximum force the anchor line must hold are then used to determine the number of anchors needed. An example calculation follows:

The maximum force the anchor lines must hold is 92.36 kN.

Five pullout test are performed. The results:

TEST NUMBER	PULLOUT FORCE
1	60 kN
2	63 kN
3	58 kN
4	57 kN
5	58 kN

The sample mean and standard deviation are calculated:

$$\text{mean } (m) = \frac{\sum_{i=1}^n F_i}{n} = 59.2 \text{ kN}$$

$$\text{standard deviation } (\sigma) = \sqrt{\frac{\sum_{i=1}^n (F_i - m)^2}{n-1}} = 1500 \text{ N}$$

The following ratios are calculated:

$$\frac{F_p}{x} = \frac{\text{max force}}{\text{sample mean}} = \frac{92.36 \text{ kN}}{59.2 \text{ kN}} = 1.56$$

$$\frac{S}{x} = \frac{\text{sample stand dev}}{\text{sample mean}} = \frac{1500 \text{ N}}{59.2 \text{ kN}} = 0.0253$$

The intersection of these two values is found in the following chart:

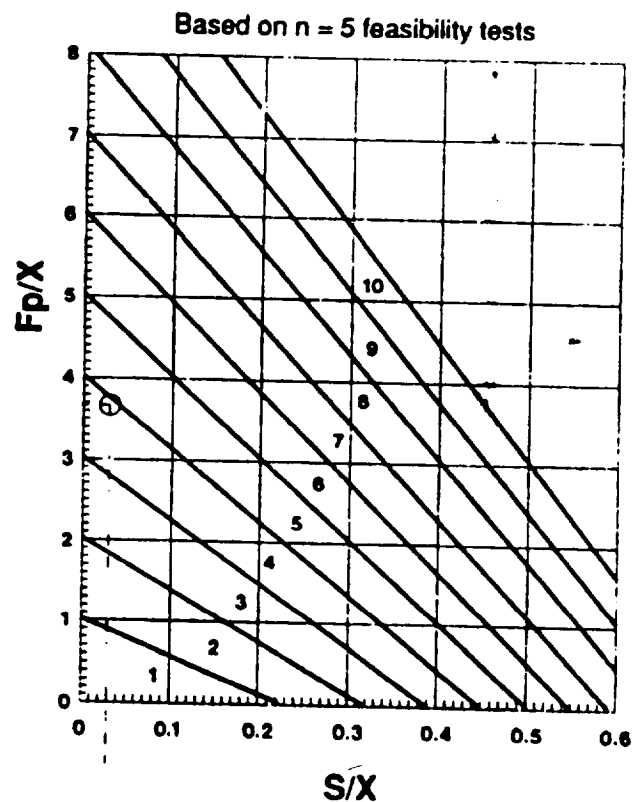


Figure 8
Method to Determine Number of Anchors in Bridle

Therefore, two anchors are needed for each anchor line.

The anchors must be installed far enough apart to insure they do not act upon the same soil mass. The zone of influence for each anchor is a cone extending up from the anchor at an angle of 45° . The anchors must be buried at least 5 ft below the surface. If the anchors are buried 2 m below the surface, there must be at least 4 m between them.

Rock Anchors

Research was done to find an anchor capable of anchoring the towers in the bedrock of Mars. All of the anchors found require the use of grout to secure the anchors and are therefore permanent. This would not work well with the METS design due to the frequent moving of the towers. Further research must be done to develop a non-permanent rock anchoring system to be used on Mars.

VE. Braking System

The module speed may be adjusted while traveling along the transport line by the use of a magnetic clutch braking system, since they are easy to use by remote control. The module is attached to the transport line by means of a pair of 0.4 meter diameter free wheels similar to those of cable cars. This transport roller wheel is mounted with a high friction material such as rubber as used in car tires to allow for greater traction on the rope. A magnetic clutch-brake may then be fitted to the wheel to allow for the reduction in speed of the module as it rolls towards to the minimum position halfway between the two towers. The position of the module may then be fixed at any point on the transport line by locking the brake system in place. This brake system could easily and effectively be controlled either in a fly-by-wire or radio controlled manner depending upon future module designs.

VF. Enabler Winch

The Enabler must be equipped with a hydraulic winch that will control the transport line. Using a hydraulic winch would be an advantage in that there is a hydraulic system all ready in place on the Enabler. The winch should have the adequate drum line pull that can lift the module when the winch is activated. The transport line will be run through four pulleys, so the winch will not see the total weight of the module. The full weight of the module was used, however, in choosing a winch for safety considerations.

The weight of the module on Earth is estimated as 313,150 N. At Mars gravity, this weight reduces to 120,000 N. A planetary hydraulic winch was chosen for its efficiency. Paccar Incorporated/Braden Carco makes a winch that has a bare drum line pull of 121,880 N and a drum capacity of 116 meters for a 2.54 cm rope. The company information can be found in the Appendix. The weight of the winch is approximately 9340 N, making it one the heavier components of the system. Using the advantages of gear ratios could reduce the speed while increasing the power of the winch, which would allow for a less powerful, lighter winch. The company does have the option of different gear ratios, but they intended this option more for lower power at higher speeds, which would not aid in weight reduction. Any alteration to the winch would have to be done independently.

VI. OPERATIONAL PERFORMANCE CHARACTERISTICS

What is the maximum acceleration that the module can impact the tower with?

For this scenario the following assumptions can be made:

$$T = 55,000\text{N} \text{ (all tensions are equal)}$$

$$T_b = 0$$

$$T_{rh} = T_r, T_{rv} = 0 \text{ (worst case scenario)}$$

Therefore the moment equation can be reduced to the following:

$$\sum M_{\text{ground at back leg}} = T_{rh} \cdot 15 \hat{i} + 2 \cdot T_h \cdot \sin(60^\circ) \cdot (15 + 11.25 + 7.5) \hat{i} - F \cdot 15 \hat{i} = 0$$

$$\sum M_{\text{ground at back leg}} = T_{rh} \cdot 15 \hat{i} + 2 \cdot T_h \cdot \sin(60^\circ) \cdot (33.75) \hat{i} - F \cdot 15 \hat{i} = 0$$

$$\therefore F_{\max} \approx 334,000 \text{ N}$$

$$a_{\max} \approx 2.8 \text{ m/s}^2$$

What is maximum length between towers?

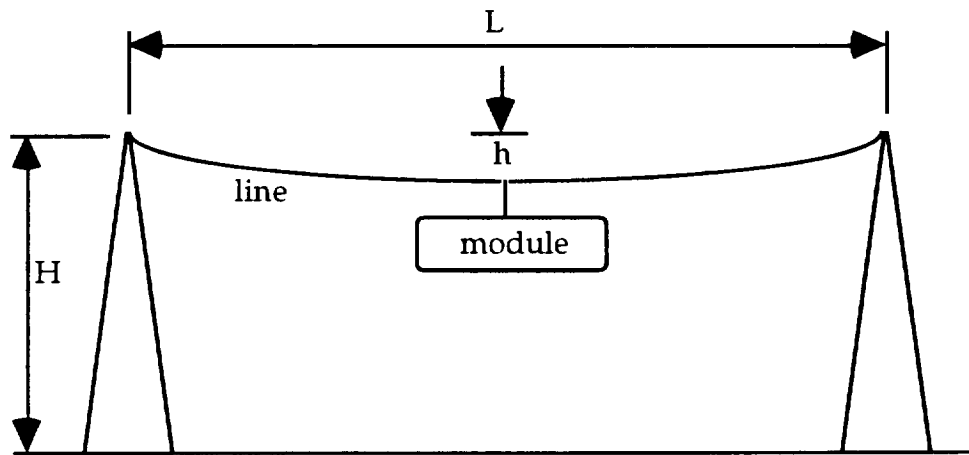


Figure 9
Transport Line Length

Above is a schematic of M.E.T.S. The distance between the tower apexes is L . Because percent elongation of the line at rupture is 2.4%, $1.024 L$ will be used as the length of the line. The amount of sag, h , was determined using Pythagorean's theorem, as seen below:

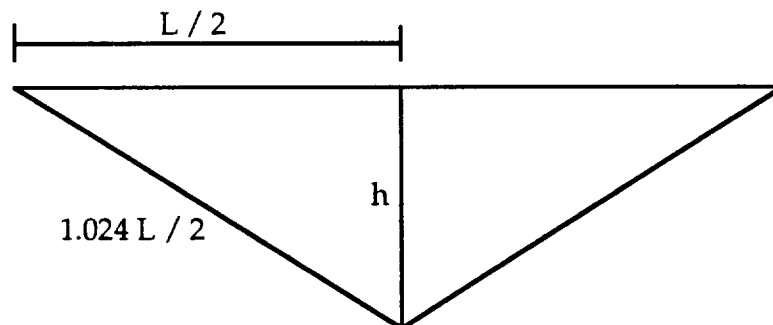


Figure 10
Sag of Transport Line

$$h = \sqrt{\left(\frac{1}{2} \cdot 1.024 \cdot L\right)^2 - \left(\frac{1}{2} \cdot L\right)^2} \quad (1)$$

The module must not contact the surface of Mars. (The length of the line connecting the module to the transport line plus the height of the module is less than six, so six is used as that length.) That is,

$$h + 6 < H \quad (2)$$

The tower legs are 20 meters long and at an angle of 60° to the surface of Mars.

Therefore, the height of the line above the surface, H , is $\frac{20 \cdot \sqrt{3}}{2}$. Realizing this and using equations 1 and 2, L can be determined:

$$\sqrt{\left(\frac{1}{2} \cdot 1.024 \cdot L\right)^2 - \left(\frac{1}{2} \cdot L\right)^2} + 6 = \frac{20 \cdot \sqrt{3}}{2}$$

$$L \cdot \sqrt{(0.512)^2 - (0.5)^2} = 11.321$$

$$L = 102.73$$

The amount of sag is determined by plugging this value into equation 1:

$$h = 11.321$$

Thus, the module will be transported 102.73 meters per trial and the lag is 11.321 meters.

The amount of stress necessary to cause failure of the line is 1200 MPa. The area of the material is:

$$\frac{OD^2}{4} \cdot \pi - \frac{ID^2}{4} \cdot \pi = 1.8 \cdot 10^{-3} \text{ m}^2$$

Therefore, the maximum allowable force is:

$$1200 \cdot 10^6 \frac{\text{N}}{\text{m}^2} \cdot 1.8 \cdot 10^{-3} \text{ m}^2 = 2.16 \cdot 10^6 \text{ N}$$

The force of the module due to gravity is 240 kN. Each portion of the line on either side of the module handles half of this force. That is, the force seen by any cross section of the line is 120 kN. Therefore, the factor of safety of the line is 9.

VII. Review of Transport Design Concepts

Block and Tackle Tower Design

A block and tackle system was considered to raise the module to the transport line. This would allow a high mechanical advantage to be attained. The block and tackle consists of two multiple-sheaved pulleys with a line running between them in a circular fashion. The amount of force necessary to lift the module would be equal to the module weight divided by the number of line passes between the pulleys. To raise the module, the lower half of the pulley system is lowered and the module is attached to it. The top half of the pulley system is attached to the tower apex. Using the Enabler's winch, the line is reeled in. This causes the lower half of the pulley system, and the module, to be raised. At this point, it is necessary to transfer the module from the vertical raising line to the horizontal transfer line. The module is transported to the second tower in the same fashion as the current design. At the next tower, the module must again be transferred to a lowering line. The module is then lowered using a second block and tackle system. The first tower is then moved to a new position and the process is repeated.

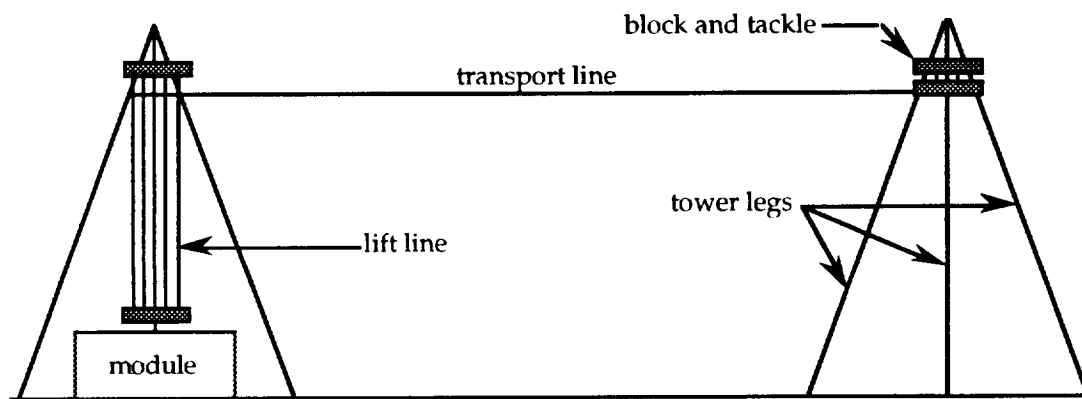


Figure 11
Block and Tackle Tower Design

This idea was dismissed because the transferring of the module between lines was determined to be inefficient and difficult to design for. Also, the weight of each pulley to be used in the system was on the order of 500 lbs (2225 N) on Earth. These facts led the group to design a system of greater efficiency and less weight. The gearing system of the current design allows the module to be raised using the transport line, negating the need for transfer between multiple lines.

Other Designs

Six initial designs were selected to analyze for practicality and design ability. They were titled tent pole, sledge, zip-line, catapult, tin can, and see-saw. Pictures of these ideas can be found in the design notebook. After using a simple list of design criteria (in notebook) and general group discussion, the six ideas were limited down to three: the tin can, a combined tent pole/zip-line idea called the zipper, and the see-saw.

The group then came up with a more detailed set of design criteria to rank the designs. Each criteria was weighted on a scale of one to five, with five being very important and one being of little importance. Capability of horizontal movement, low mass, a high mechanical advantage, reliability, and the ability of the design to be run by the Enabler were weighted as the most important criteria. The three ideas were ranked either one, three, or nine, in order to clearly identify the best choice. The criteria selection table is seen below, Figure 9. If all three designs received identical scores, that criteria was removed from consideration. This eliminated the criteria of horizontal movement, being run by the Enabler, and cost.

The total scores for the ideas were 166 for the tin can, 328 for the zipper, and 246 for the see-saw. This confirmed the group's belief that the zipper would be the best idea.

	H O R I Z O N T A L M O V E M E N T	M A S S	M E S C H A N I C A L T Y A D V A N T A G E	R E L I A B I L I T Y	R U N B Y L E V E R	M U L T I B I L I T Y (S E T U P)	S T A B I L I T Y	T E R R I T O R I A L D I S T A N C E	V E R T I C A L M O V E M E N T	E A S Y S E N S I T I V E A C C U R A C Y	H O R I Z O N T A L A C C U R A C Y	M U L T I T A S K I N G (A F T E R S E T U P)	S I Z E	V E R T I C A L A C C U R A C Y	N U M B E R O F A R T S	S E T U P T I M E	T R A N S P O R T E F F I C I E N C Y	C O S T	T O T A L	
WEIGHTING	5	5	5	5	5	4	4	4	4	3	3	3	3	3	3	2	2	2	1	
"TIN" CAN	9	1	1	3	9	1	9	1	1	9	3	3	1	1	3	9	9	3	3	166
ZIPPER	9	3	9	9	9	9	3	9	9	1	9	9	3	9	1	1	3	3	3	328
SEE-SAW	9	3	9	9	9	3	9	3	3	3	9	9	3	3	3	3	3	3	3	246

Figure 12
Criteria Selection Chart

VIII. RECOMMENDED FUTURE TASKS AND INVESTIGATIONS

There are several areas that need to be developed further to insure the reliable execution of the METS system. First of all, the Enabler design needs to incorporate all of the functions needed by the METS project, such as the assembly of the tower segments, hoisting the module, anchoring the tower, moving the towers and directing the transport of the module. As designs for the Enabler are redefined and completed the METS operations and characteristics need to be reevaluated to determine if more optimal systems could be used.

As the design of Space Station *Freedom* truss system is continued, changes occurring may affect the METS project. The METS system was designed to be interchangeable with the trusses in the Space Station in order to increase their multifunctionality. In addition, this reduces the different assembly methods and spare parts.

Another facet of the project that should be continued is to prepare the METS system for other functions on Mars. For example, if mining is going to be conducted on Mars, the tower system may need to be modified slightly. When all future tasks for the METS system are known, the tower system may need to be redesigned in order to optimize the requirements of all of the future tasks.

When more information on Mars' soil conditions is obtained, the current anchor system may need to be revamped. The anchor system will still have to be altered depending upon the local soil conditions, however, more relevant information is needed.

Research should be conducted concerning the response of the METS system material to radiation. The material was selected with resistance to radiation in mind, but without comparable material testing on Mars, the life span of the material will be uncertain. If testing results with too short of a life span, perhaps a coating to protect the tower and rope material should be included within the design.

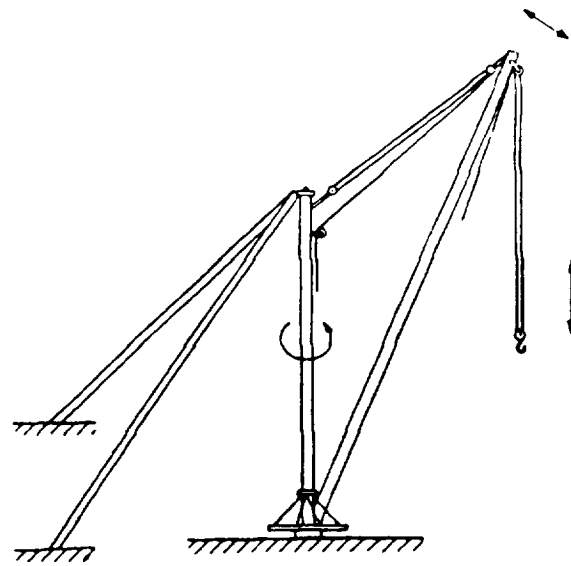
IX. RESEARCH

IXA. Rigging and Rousting [6],[7]

To gain a better understanding and awareness of methods to efficiently transport or move objects, extensive research into rigging and rousting methods was completed. Riggers are known for their ability to construct or move objects with little equipment and very little force. Due to the high cost of shipping items to Mars, the reduction of the weight of the transport system is one of the most important factors contributing to the design. Therefore, some goals of the transport system include using high mechanical advantages, utilizing a minimum number of parts, and being lightweight.

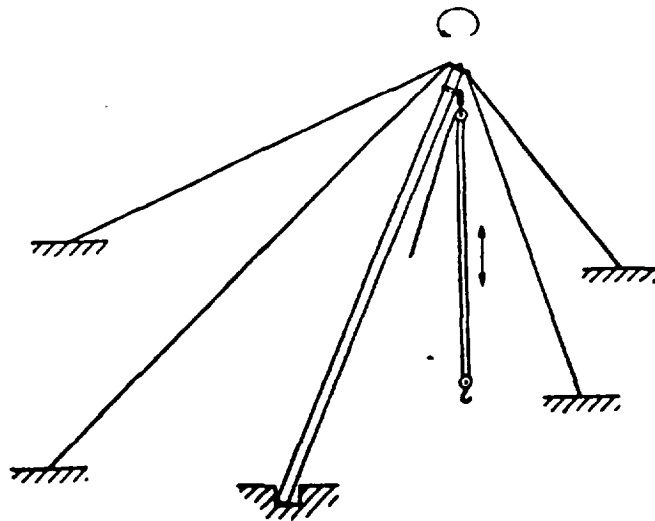
Cranes and derricks used for rigging provide insight into ways to anchor and support structures. In addition, the design of the trusses in rigging equipment can be applied to the transport system. Information was also obtained from rigging handbooks on ways to support a concentrated load like that of the module. The use of guys and ropes to control the object being moved is another advantage that can be used for the design. By applying the tested and proven methods that riggers use, even more confidence will be behind the design of the transport assembly.

Several different rigging methods to unload and set-up equipment were analyzed. For example, a few of the ways riggers unload or set-up equipment is through the use of derricks, cranes, and hoists. In addition, more simple objects like levers, slings or crowbars are used. Some of the cranes that riggers use include the "stiff-leg derrick". This crane takes advantage of the lever arm to raise and lower objects, as seen in the drawing below. The two rear legs support and anchor the derrick. The direction of motion is controlled through the use of guys.



Stiff-leg Derrick
Figure 13

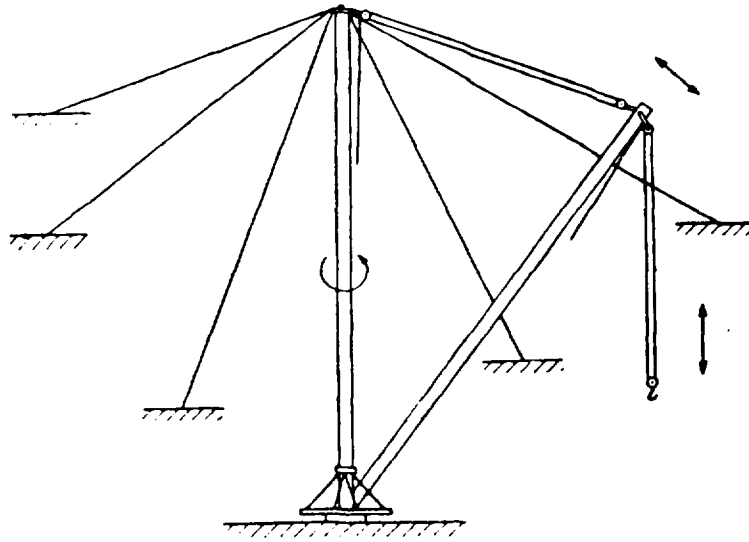
The "guyed derrick" is very similar to the "stiff leg derrick" except instead of having two rear poles all support and anchor is provided by guys. The "guyed derrick" can raise and lower objects and also transport them horizontally through the use of a lever arm.



Guyed Derrick

Figure 14

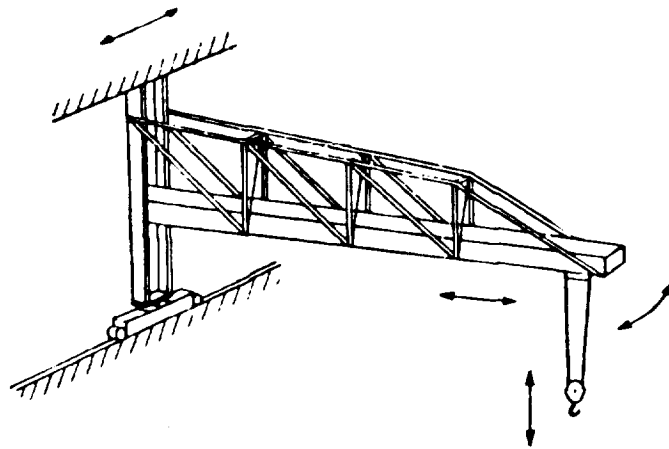
"Gin-poles" are another very similar type of derrick. "Gin-poles", however, support the object directly from the top of the pole rather than using an extended arm.



Gin-pole

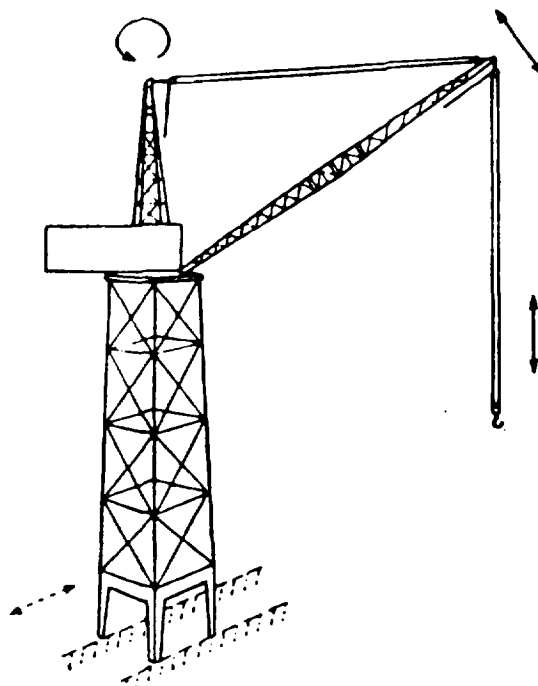
Figure 15

Several different types of crane setups are used in rigging. Some are just simple one leg cranes like the "jib crane" while others like the "gallows frame" have a structure similar to a sawhorse. "Wall cranes" and "tower cranes" as shown below are also very simple devices.



Wall Crane

Figure 16



Tower Crane

Figure 17

IXB. Surface Characteristics and Soil Considerations [5]

The Surface of the planet Mars varies greatly in its surface characteristics. All of these characteristics may be experienced by a surface mission. Therefore, it is of primary importance that any surface transport system be design to function in all possible extreme cases that the surface may present.

The Soil of Mars is mostly of a sand based composition. A simple yet accurate model details the surface of the planet as a small layer of fine grain sand covering bedrock. Rocks or boulders cover the surface of the planet. The density of these rocks may be approximated as varying inversely with the size of the rocks. The stability of either the sand dunes or small bedrock outcroppings cannot be assumed. Sand dunes shift daily in the high wind surface environment. Bedrock outcroppings may be hollow or unstable. Since it is assumed that no large vehicles have ever crossed the surface of the planet, some areas of quick sand or sink holes undoubtedly exist.

However, these acute problems should be rare in their frequency and should not prove catastrophic to surface transport. The inhospitability of the surface does necessitate the implementation of a plan that may be re-configured at the mission site. Site inspection may indeed reveal the necessity for changes in the path or manner of module transport. Maximum flexibility is therefore a concern for the general case of module transport across the surface of the planet.

The structural stability of the METS design relies upon the use of anchors to balance the moments produced on the towers by module transport. The specific characteristics of the soil in the immediate location surrounding the towers is therefore a primary design concern. The METS design takes into account two predominant possibilities that allow for nearly any combination of local surface characteristics to be tolerated. The two possibilities of local soil are taken to be:

- Predominantly sand soil consisting of loose granules.
- Predominantly exposed structural Bedrock.

IXC. Mars Atmosphere Considerations [2]

The lower atmosphere of Mars extends from zero to 140 km above the surface. The only major constituent of the atmosphere is CO₂. Minor constituents are water vapor, dust, CO, O₂, and O₃. The mean relative humidity is 50%; Mars lacks oceans and intense cloud formations. The temperature of the Mars atmosphere is dependent upon the amount of dust, the latitude, the season, the local time, and the topography. A typical surface temperature range at 0° latitude is 200 to 270 K (-100 to 26 °F). Because the dust heats more quickly than the rest of the atmosphere, the atmosphere is frequently subject to uneven heating. Thus, wind storms are very frequent and happen daily. Velocities of up to 150 m/s (335 mph) have been measured. Theoretical values of wind velocity determined from Earth-based observations are provided below:

maximum surface wind	100 m/s	(220 mph)
maximum vertical wind	13 m/s	(30 mph)
average zonal wind	25 m/s	(56 mph)
average meridial wind	1.3 m/s	(3 mph)

A typical range for surface pressure is 5 to 13 mb (5×10^{-3} to 3×10^{-2} atm). Therefore the force induced by the wind is much less than what would occur on Earth.

IXD. Vendor Data

McNissick Snatch Blocks

NEW IMPROVED LIGHT CHAMPION



418
WITH HOOK



419
WITH SHACKLE



404
TAIL BOARD

- Forged alloy heat treated hooks.
- Forged steel swivel toes, yokes and shackles.
- Hook and shackle assemblies on 6" through 18" sizes can be Interchanged.
- Can be furnished with bronze bushings or roller bearings.
- Opening feature permits insertion of rope while block is suspended from gin-pole.
- Can be furnished with SS-4055 hook latch.
- Pressure lube fittings.
- 3" thru 18" 418 and 419 blocks have exclusive bolt retaining spring to assure no lost bolts.
- Fatigue rated.



SEE APPLICATION AND WARNING INFORMATION

On Pages 140 - 147

"PATENTED IN USA"

Sheave Diameter (in.)	Bearing Code	Block No.			Wire Rope Size (in.)	Working Load Limit (lbs.) (5304)	Weight (Each) (lbs.)		
		418 with Hook	419 with Shackle	404 Tail Board			418 with Hook	419 with Shackle	404 Tail Board
" 3	BB	169043	†169212	177132	5/16	2	4.3	3	3
" 3	BB	108038	†108037	102016	5/16	2	4.3	3	3
" 4 1/2	BB	169069	169249	167866	3/4	4	11	12	6
" 4 1/2	BB	108065	108064	102025	3/4	4	11	12	6
6	BB RB	168419 199844	169258 202858	177203 177258	3/4	8	26	27	15
6	BB RB	108127 108154	108126 108153	102098 102114	3/4	8	26	27	15
8	BB RB	199571 199715	189301 202710	177294 187893	3/4	8	33	34	21
8	BB RB	108225 108252	108224 108251	102189 102187	3/4	8	33	34	21
10	BB RB	199788 199840	202872 189338	177409 177483	3/4	8	41	42	29
10	BB RB	108323 108350	108322 108359	102230 102258	3/4	8	41	42	29
12	BB RB	189189 199911	202981 169347	178890 178934	3/4	8	48	49	36
12	BB RB	108421 108458	109420 109457	102301 102329	3/4	8	48	49	36
14	BB RB	184920 199948	189356 167857	—	3/4	8	55	56	—
14	BB RB	108528 108548	109527 109545	—	3/4	8	55	56	—
16	BB RB	199975 200008	203041 203087	—	3/4	15	130	135	—
16	BB RB	108608 108628	109607 109625	—	3/4	15	130	135	—
18	BB RB	200099 200151	203130 203178	—	3/4	15	150	155	—
18	BB RB	108644 108662	108643 108661	—	1	15	150	155	—

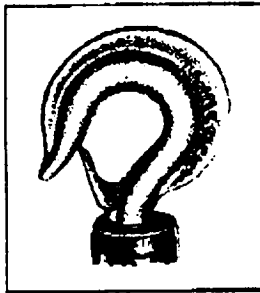
* Ultimate Load is 4 times the Working Load Limit.

** Available in Bronze Bushed only. 3" and 4 1/2" have self lubricating Bronze Bushing.

† Fitted with 1 1/4" ID Swivel Eye.

†† May be furnished in other wire rope sizes.

SUPER CHAMPION



Available with hook latch.

- Drop forged, heat treated swivel hook or swivel shackle.
- Hook and shackle assemblies on 8" through 14" sizes can be interchanged.
- Can be furnished with bronze bushings or roller bearings.
- Pressure lube fittings.
- 8" thru 14" 430 and 431 blocks have exclusive bolt retaining spring to assure no lost bolts.
- Can be furnished with SS-4055 hook latch.
- Fatigue rated.



430
WITH HOOK



431
WITH SHACKLE



407
TAIL BOARD

**SEE APPLICATION AND
WARNING INFORMATION**
On Pages 140 - 147

Sheave Diameter (In.)	Bearing Code	Block No.			Wire Rope Size † (In.)	Working Load Limit (Metric tons)	Weight Each (lbs.)		
		430 with Hook	431 with Shackle	407 Tail Board			430 with Hook	431 with Shackle	407 Tail Board
8	BB RB	208448 169882	169891 209214	184286 168017	1	20	75	87	42
8	BB RB	120023 120041	121022 121040	103523 103541	1 1/4	20	75	87	42
1J	BB RB	208475 208509	209232 209269	184311 184348	1	20	89	101	55
10	BB RB	120096 120112	121095 121111	103603 103621	1 1/4	20	89	101	55
12	BB RB	208536 208554	169917 209303	184375 184393	1	30	103	115	70
12	BB RB	120176 120194	121175 121193	103685 103701	1 1/4	20	103	115	70
14	BB RB	208572 208690	209321 170424	184419 184437	1	20	123	135	90
14	BB RB	120256 120274	121255 121273	103765 103783	1 1/4	20	123	135	90
18	BB RB	208689 206732	208410 209465	184552 184605	1	25	240	260	165
18	BB RB	119482 119491	119561 119570	119641 119650	1 1/4	25	240	260	165
20	BB RB	— 206787	209483 169864	184623 184650	1 1/4	30	375	400	215
20	BB RB	119507 119516	119589 119598	119669 119678	1 1/4	30	375	400	215
24	BB RB	208812 208858	209526 209553	184687 184721	1 1/4	30	450	475	290
24	BB RB	119525 119534	119605 119614	119687 119696	1 1/4	30	450	475	290

* Ultimate Load is 4 times the Working Load Limit.

† May be furnished in other Wire Rope sizes.

NOTE: When ordering, please specify: size, block number, hook or shackle, bronze bushed or roller bearing, and wire rope size.

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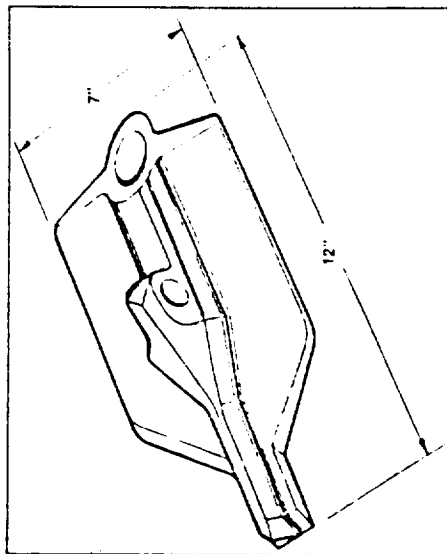


Figure 3—Manta Ray anchor

Drive rods (sometimes called drive gads) transmit the reciprocating force from the impact hammer to the anchor and must be customized to fit the anchor. Most hydraulic and pneumatic hammers require a rod 1.125 or 1.25 inches in diameter. Some smaller hammers and the gasoline hammers use a rod 0.875 inch in diameter. The end of the rod that is inserted into the anchor needs to be machined for a tight clearance. If the clearance is too small, however, the anchor may become seized on the rod during installation. The rod should also be machined so that the end of the rod does not touch the bottom of the socket in the anchor.

Drive rods can be obtained in 2.5-, 4.0-, and 5.5-foot lengths. The rods used for driving Manta Ray anchors are designed so that sections may be coupled together; rods for other anchors are a fixed length. A disadvantage of using fixed-length rods is that the depth an anchor is driven to is limited by the length of the rods. Also, if a 5.5-foot rod is used to start the driving operation, the operator will be required to hold the hammer about 6 feet above the ground. This may require standing on something to gain the proper working elevation. If the rods are shorter and additional sections can be added as the anchor is driven, the operator is usually working with the hammer below shoulder height, which is easier and safer.

Many gasoline- and hydraulic-powered portable augers can auger holes 4 to 8 inches in diameter. Auger extension flights can be obtained in several lengths and diameters to suit various conditions. Carbide tips are recommended for most forest soils. Manufacturer's specifications on installation equipment are given in appendix 3.

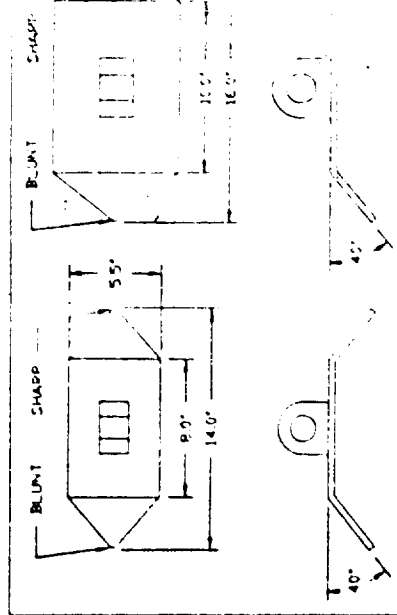


Figure 4—5-inch and large sledge anchors

The installation procedures differ with the type of soil and anchor (such as a 2-inch Arrowhead) in soft soils, the anchor is driven with a drive rod and a sledge hammer or with a driving device such as a steel fencepost. The drive rod is inserted into the hole and the anchor is positioned so that the cable faces the direction of pull. The desired angle until it cannot be driven further or the desired angle or "keyed" so that the major plane of the anchor will be about 90 degrees angle of pull. This is done by pulling the anchor until the anchor is pulled 8 to 12 inches out of the ground.

For the larger Arrowheads (6-inch size or larger) and Manta Ray anchors, or gasoline-driven impact hammer is needed to install the anchor. The procedure is the same as for the drive rod and sledge hammer. The hammer is placed on the drive rod before the rod is inserted into the hole.

In denser soils, such as dense clays, a pilot hole can be augered in. With a Manta Ray anchor, for example, a 4-inch pilot hole is at least 6 inches deeper than the design depth. This leaves an area of loose soil to accumulate in. After the hole is augered, by using the pilot hole as a guide. Because the Manta Ray anchor is 3 inches of its width is driven through the undisturbed soil. Once the desired depth, the rod is pulled out and the hole is filled with soil. The anchor must be set as described above.

Installation Procedures Anchors

Anchor Information

Solution

Using the first method, we estimate the maximum force exerted on the anchorage will be two-thirds of the rated breaking strength or 128,000 pounds. The sample mean and standard deviation are 34,920 and 1008 pounds, respectively. We then calculate the two ratios:

$$F_p/X = 128,000/34,920 = 3.67$$

and

$$S/X = 1,008/34,920 = 0.03.$$

Because five tests were done, we use the chart for $N=5$ (fig. 6) and read that four anchors are needed.

Using the second method, we divide the rated breaking strength of the wire rope by the mean of the pullout forces for the feasibility tests:

$$192,000/34,920 = 5.5 \text{ anchors required.}$$

According to the second method, six anchors are needed.

In this example, the first method shows that fewer anchors are required, but the first method will not always result in smaller estimates. Large differences in the test results will cause the number of anchors required by the first method to be higher but will not affect the results given by the second method.

Multiple-anchor holding capacity—One of the assumptions that the calculations in example 1 depend on is that the bridle design is 100 percent efficient. In fact, the holding capacity of a group of anchors is not usually equal to the holding capacity of one anchor multiplied by the number of anchors in the group (Kovacs and Yokei 1979). Kovacs and Yokei (1979) point out:

Many efficiency ("efficiency" is the ratio between the group capacity and the sum of the capacities of the individual piles) formulas are available for the unwary engineer to use in computing the ultimate capacity of a pile [or anchor] group. None of these formulas take into account the factors that actually govern the ultimate capacity of the...group itself. Likewise, there are no hard and fast rules to use when predicting the pullout capacity of multiple anchors.

Two factors affecting the capacity of a multiple-anchor cluster are the degree to which loads are shared among the individual anchors of the cluster and the degree to which individual anchors in a cluster act on separate soil masses. If loads are not adequately shared among clustered anchors, then one anchor may reach its maximum load capability before the others, and the maximum holding capacity of the entire anchorage will be some fraction of the capacity of a 100-percent-efficient anchorage. Because the load capacity of a soil anchor depends partially on the soil mass mobilized, two anchors sharing the same soil mass will have less ultimate capacity than if they operated on separate soil masses.

How much loads are shared among clustered anchors is affected by soil characteristics, the depth of the anchor installation, and the design of the bridle. Anchors installed in soft, highly disturbed soils—In general, soils having a large capacity to be compressed—will have greater potential for equalizing loads among several anchors in a cluster.

Figure 7 depicts the results of tests on Arrowhead anchors that were performed by Foster-Miller, Inc., Waltham, MA, in 1985-86. The graph shows that the mean pullout force for single-anchor installations was 9,400 pounds; however, when more than one anchor was installed in a bridged cluster, each additional anchor added only 4,100 pounds of pullout capacity. These anchors were installed 5 feet deep, and the anchors of each cluster were within 5 feet of each other. All the anchors in a cluster were clearly acting on a common soil mass, which undoubtedly contributed to the poor efficiency of the installation.

Distance between anchors—Anchors must be installed far enough apart so that they do not bear on the same soil mass. To ensure this, a zone of influence is defined around each anchor. This zone of influence is at the intersection of the ground surface with a cone extending up from the anchor at an angle of 28 to 35 degrees for cohesive soils (fig. 8). In granular soils, the angle of the cone is nearly equal to the angle of internal friction, which for most conditions is less than 45 degrees (table 4). Therefore, a conservative approach to determining the zone of influence at the ground surface is to assume that the zone extends to a distance equal to the depth of installation around the anchor. If the anchor is installed 5 feet deep, for example, the soil within a radius of 5 feet from the hole will have an influence on its holding capacity.

Installation depth—The depth of installation for any of the three anchor types is determined from soil strength and the results of the feasibility tests. In any case, the minimum depth should be 4 feet for the Arrowhead anchor, 5 feet for the Manta Ray and small soil toggle anchors, and 8 feet for the large soil toggle anchor.

The designed depth of installation should be at least that of the feasibility tests. If this cannot be done, the installer should move a few feet and try to attain the design depth. If the design depth still cannot be achieved, new feasibility tests may have to be done for a shallower depth.

Installation angle—The angle of installation is decided after the direction of pull relative to the slope of the ground is determined (fig. 5). In general, for pulls that are going downslope, the anchor is installed perpendicular to the ground. As the angle of pull nears perpendicular to the ground, the anchor is installed vertically. As the direction of pull swings uphill, the anchor should again be installed perpendicular to the slope of the ground. The objective is to avoid having the direction of pull in line with the direction of installation and to maximize the distance of undisturbed soil between the installed anchor and the ground plane in the direction of pull.

Table 3—Installation equipment and access guide

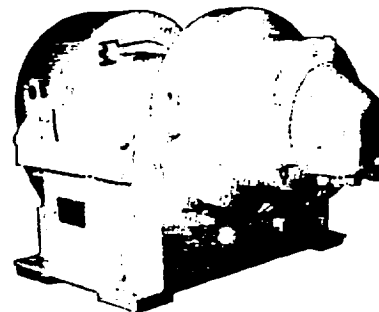
Anchor	Recommended installation equipment	Portability^a
Large soil toggle	Hydraulic Little Beaver with 8-inch auger	Can be mounted on sled or trail machine for remote access
Small soil toggle	Hydraulic or gas Little Beaver with 6-inch auger	Can be mounted on sled or trail machine for remote access
Manta Ray: Augered pilot hole	Gas Little Beaver with 4-inch auger plus gas, hydraulic, or trail pneumatic driving hammer	Can be mounted on sled or trail machine; for remote access use portable HPU with hydraulic or gas hammer such as Pionjar
Drilled pilot hole	Hydraulic, pneumatic, or gas drill with 2-inch-in-diameter rock bit; gas, hydraulic, or pneumatic driving hammer (some hydraulic and gas hammers will drill and drive)	Portable gas hammer, such as Pionjar, can drill and drive and can be carried in a backpack; portable HPU can be used with hydraulic hammer and drill; pneumatic equipment is not portable
No pilot hole	Hydraulic, pneumatic or gas hammer	Same as Manta Ray—drilled pilot hole
Arrowhead: Augered pilot hole	Same as Manta Ray—augered pilot hole except a 2-inch diameter auger would be used	
Drilled pilot hole	Same as Manta Ray—drilled pilot hole	
No pilot hole	Same as Manta Ray—no pilot hole	

^a All installation equipment can be transported by helicopter.

SERIES 40

Planetary
Hydraulic Gear

BARE DRUM LINE PULL (LBS.)	DRUM DIMENSIONS (IN.)			WIRE ROPE SIZE (IN.)	DRUM CAPACITY (FT.)
	BARREL DIAMETER	FLANGE DIAMETER	BARREL LENGTH		
44,000	12.00	22.00	12.00	$\frac{7}{8}$	258
				1	233
				$1\frac{1}{8}$	160
44,000	12.00	22.00	18.00	$\frac{7}{8}$	388
				1	360
				$1\frac{1}{8}$	248
44,000	12.00	22.00	24.00	$\frac{7}{8}$	538
				1	488
				$1\frac{1}{8}$	366
44,000	12.00	22.00	30.00	$\frac{7}{8}$	678
				1	616
				$1\frac{1}{8}$	425
27,400	20.00	30.00	13.20	$\frac{3}{4}$	610
				$\frac{7}{8}$	425
				1	380
27,400	20.00	30.00	19.20	$\frac{3}{4}$	906
				$\frac{7}{8}$	633
				1	567
27,400	20.00	30.00	25.20	$\frac{3}{4}$	1200
				$\frac{7}{8}$	840
				1	755
27,400	20.00	30.00	31.20	$\frac{3}{4}$	1496
				$\frac{7}{8}$	1050
				1	943



Options:

- Motors
- Gear Ratios
- Drum Sizes
- Two Speed
- Free Fall

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2531

Downstairs - 5040

United States Patent [19]

Morita et al.

[11]

4,369,714

[45]

Jan. 25, 1983

[54] CABLE CAR DOCKING SWAY ARRESTER MECHANISM

[75] Inventors: Masaki Morita, Yokosuka; Michio Yamaguchi, Yokohama; Hiroyuki Asano, Tokyo, all of Japan

[73] Assignee: Nissan Motor Co., Ltd., Yokohama, Japan

[21] Appl. No.: 209,027

[22] Filed: Nov. 21, 1980

[30] Foreign Application Priority Data

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 Apr. 7, 1980 [JP] Japan 55-45790[U]
 Apr. 8, 1980 [JP] Japan 55-46416[U]
 Sep. 24, 1980 [JP] Japan 55-135708[U]
 Sep. 26, 1980 [JP] Japan 55-137452[U]

[51] Int. Cl. B61B 3/02; B61B 7/06;
 B61B 12/04

[52] U.S. Cl. 104/250; 104/93;
 104/172 S; 104/173 R; 105/150; 105/329 S

[58] Field of Search 104/112, 173 R, 173 ST,
 104/249, 250, 251, 93, 172 S; 105/150, 329 S,
 329 SC

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Primary Examiner—Robert B. Reeves

Assistant Examiner—Howard Beltran

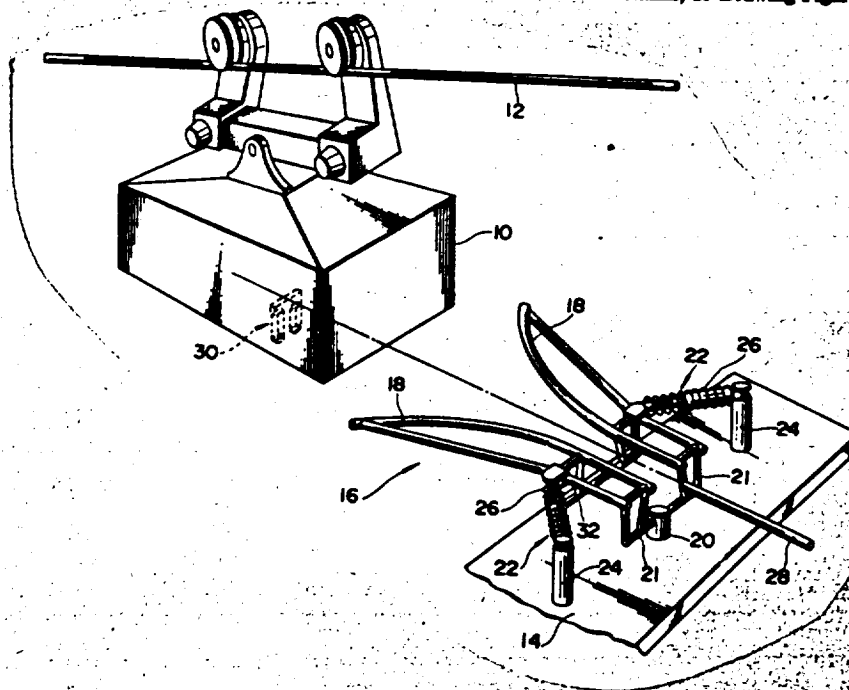
Attorney, Agent, or Firm—Lane, Aitken, Kice & Kananen

[57]

ABSTRACT

A cable car type vehicle arrester features a pair of trumpet bars which are interconnected by a link which either maintains the distance between the bars constant or reduces same upon one of the bars being deflected outboard of its home or rest position. This reduces the free swinging time of the vehicle between bars and increases the distance through which the bars subsequent to the initial deflection are deflectable by the vehicle. This accordingly increases the stroke of shock absorbers associated with the bars increasing the conversion of the kinetic energy of the vehicle. Casters can be provided to support the bars to allow longer lighter bars with less robust bearing and structural members. The casters can be run on a corrugated surface to cam the bars vertically further increasing the kinetic energy conversion and endow a self-centering action on the arrester. Extensions on the trumpet bars which are co-extensive with guide rails on the station are simultaneously engageable with a roller or rollers on the vehicle for forcing the trumpet bars back to a centered or home position.

10 Claims, 15 Drawing Figures



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PREFACE

The objective of this design guide is to present information for use in selecting and specifying Kevlar aramid ropes for ocean engineering and construction applications.

This guide is based on available technical data which are representative of state-of-the-art knowledge of the material, rope design, manufacturing processes, test procedures, and application engineering.

It discusses the unique properties of aramid rope, which include:

- (a) very low stretch.
- (b) high tensile strength.
- (c) very high strength-to-weight ratio.
- (d) excellent fatigue resistance.
- (e) good performance over large temperature range.
- (f) low creep.
- (g) no shrinkage.
- (h) minimum snapback hazard.
- (i) good chemical stability.

The negative aspects of the fiber also covered include:

- (a) low transverse modulus.
- (b) self-abrasion of the fibers.
- (c) high material cost.

The various constructions available are compared with similar constructions of other rope materials including wire rope, and comments are made on the relative merits of each for different ocean-engineering applications. These comparative data between aramid fiber rope and rope made from other materials are an aid to help support objective decisions by an engineer in selecting rope materials. Since cost factors are important considerations in the selection process, the relative cost of comparable ropes of various materials are established.

Table 1-2 -- Comparison of Yarn, Filament, and Wire Nominal Properties

Material	Tensile Strength (psi $\times 10^3$)	Elastic Modulus (psi $\times 10^6$)	Elongation at Rupture (%)	Density (lb/in ³) (gm/cm ³)	Specific Tensile Strength 10 ⁶ (in)	Specific Modulus 10 ⁸ (in)	Dielectric Constant	Melting Point °F (°C)
Kevlar 29**	400	9	4.0	0.052 1.44	7.7	1.73	3.4	800 (430) (Chars)
Kevlar 49**	490	16.0	2.4	0.052 1.44	7.7	3.08	3.4	800 (430) (Chars)
Steel Wire	300	29.0	1.1	0.285 7.86	1.8	1.02	—	2250 (1400)
Dacron Polyester Type 68**	168	2.0	15.0	0.050 1.38	3.2	0.40	—	480
Nylon Type 728**	143	0.73	19.0	0.041 1.14	3.5	0.12	—	450 (232)
Rayon**				0.055				
Viscose**	70	0.4	17.0	1.52	1.3	0.07	—	(Chars)
S Glass*	400	12.4	3.1	0.09 2.50	4.4	1.38	4.5	1540 (840)
E Glass*	575	10.5	3.1	0.092 2.55	6.3	1.14	4.5	1290 (700)
H S Graphite*	350	35.0	1.9	0.054 1.50	6.5	6.48	5.0	6600 (3650)

*ASTM D2343 (Resin Impregnated)

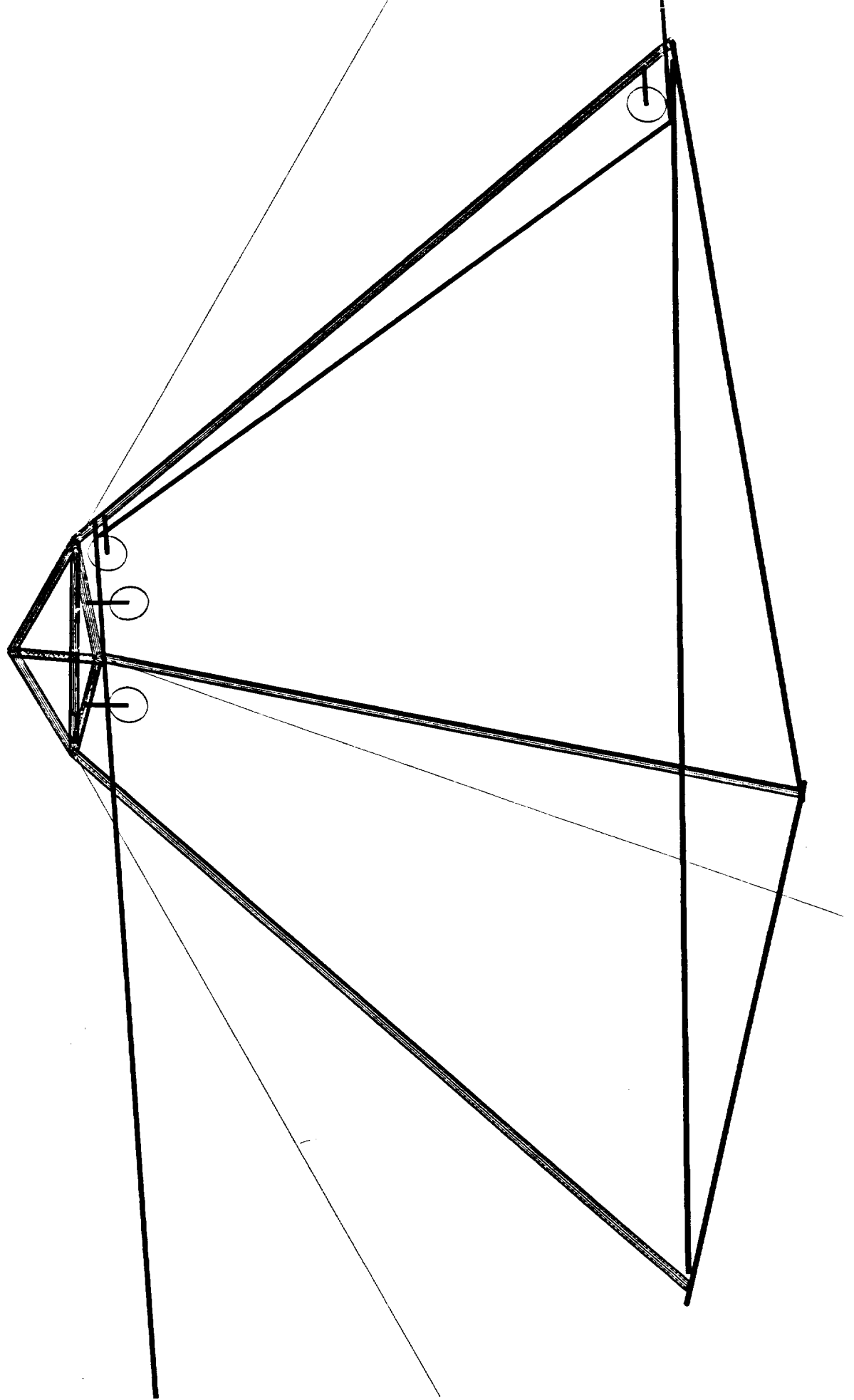
**Twisted Yarn Properties

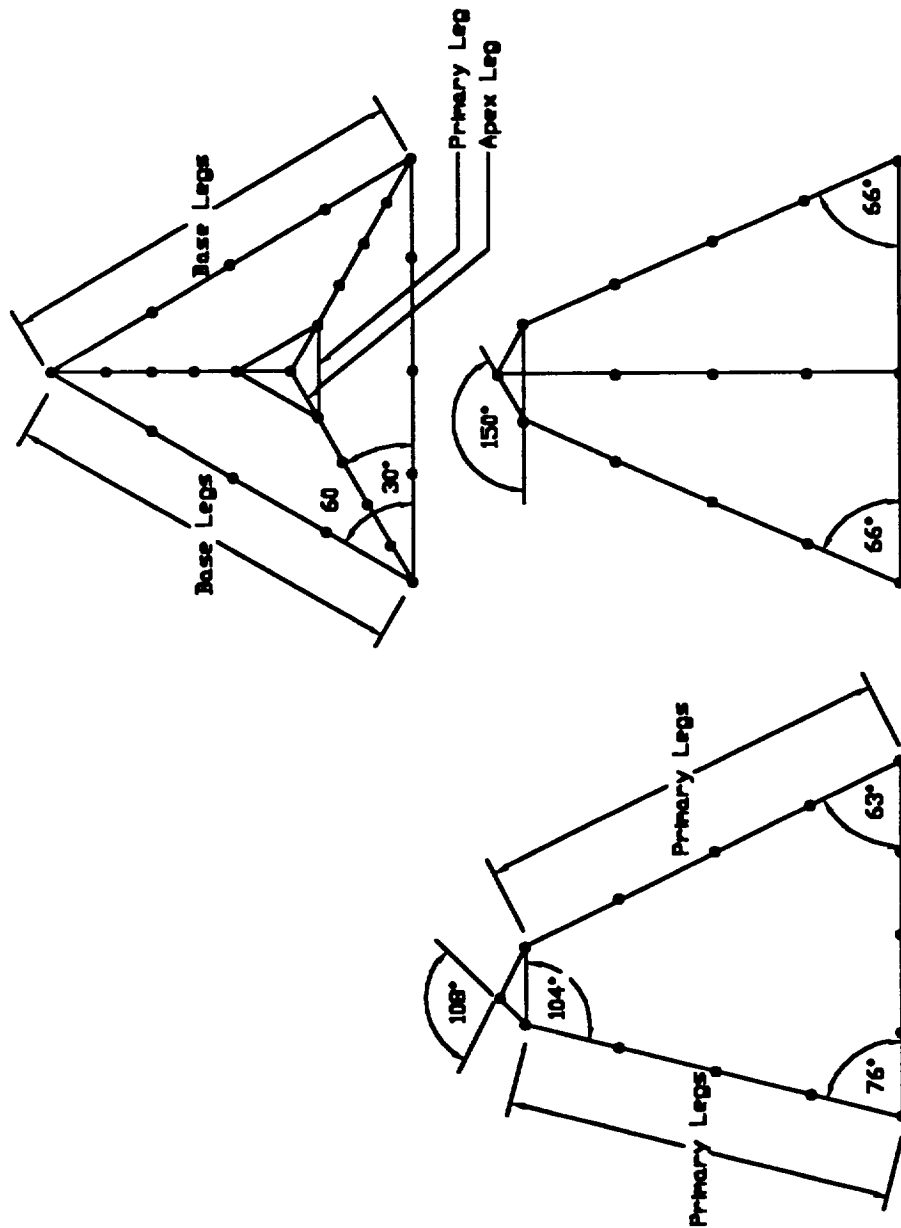
Table 1-3 -- Tension-Tension Fatigue of Kevlar 29 Yarns

Construction	Cycled Between % of Ult. Tensile Strength		Cycles	% Strength Loss
	Low	High		
1500 Denier/ 2 Ply Cords	45	74	1000	0
2 Ply Cords	29	52	1000	0
2 Ply Cords	8	31	1000	0
1500 Denier Yarn	0	10	13 $\times 10^6$	5

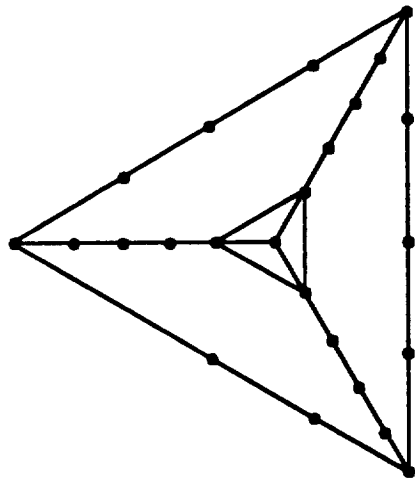
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X. DETAILED DESIGN DRAWINGS

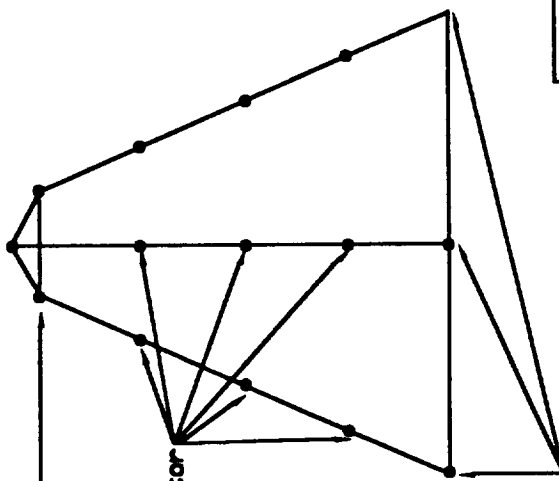




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Concept Design Sheet 1
Date 11/23/93 Scale None



Apex Connector



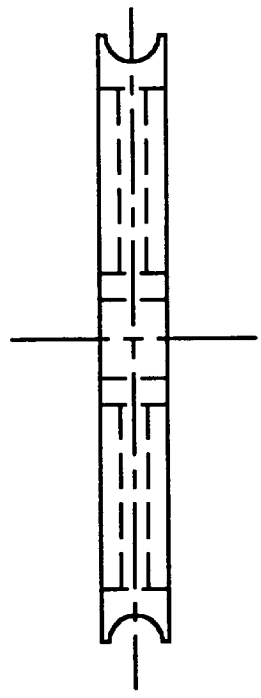
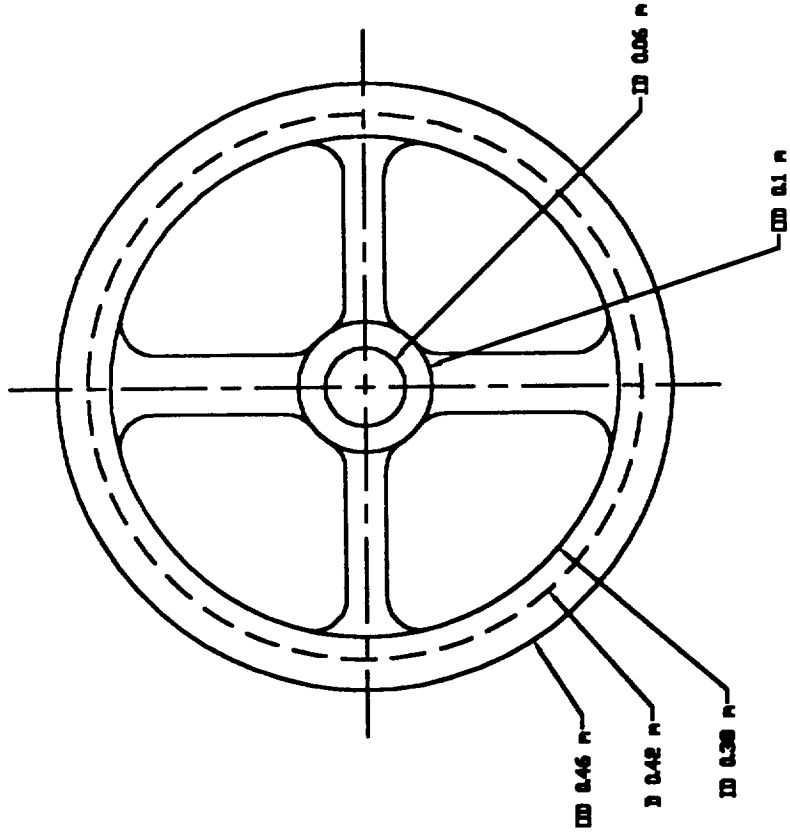
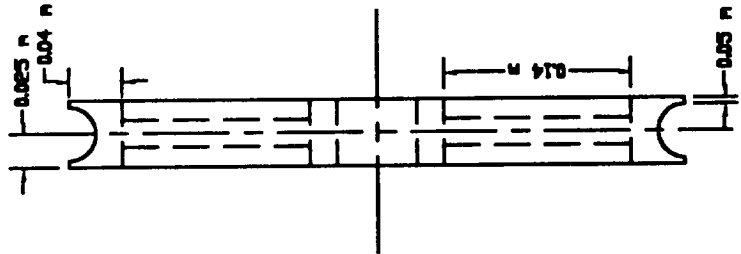
Delta Connector

Primary Connector

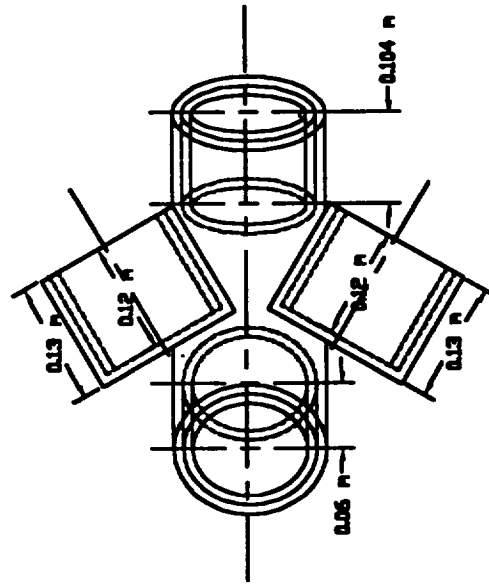
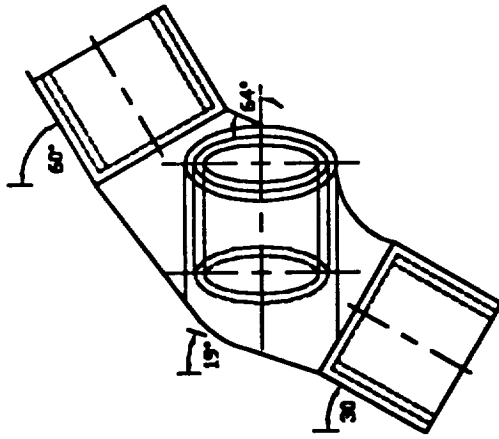
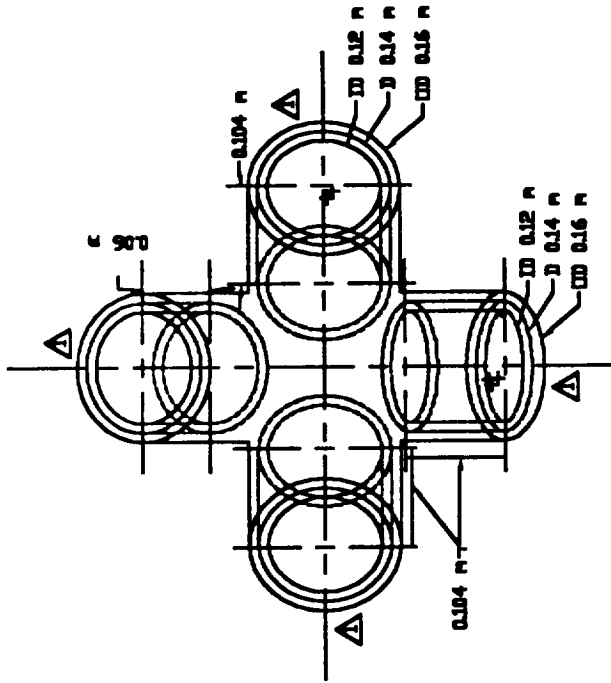
Base Connector

Secondary Connector

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Concept Design Sheet 2
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Parnt Name, Delta Pulley
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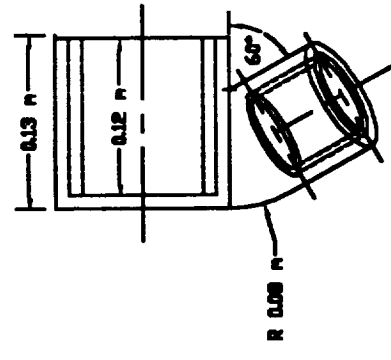
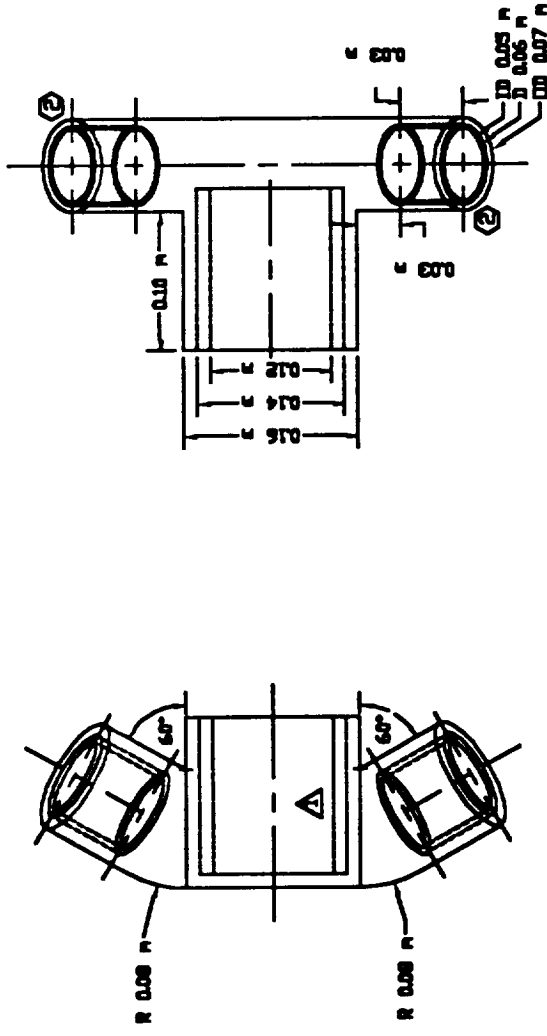
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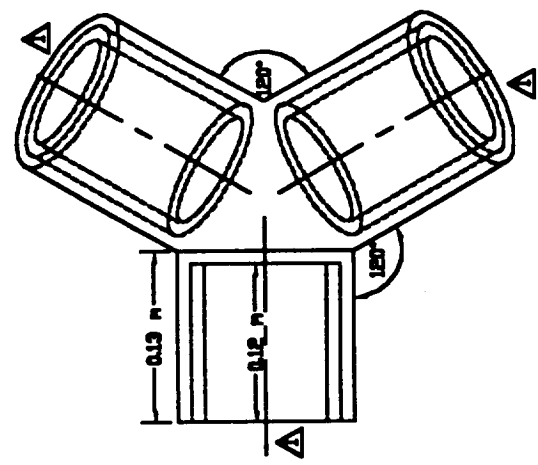
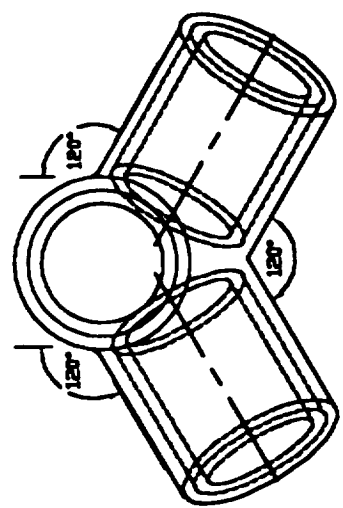
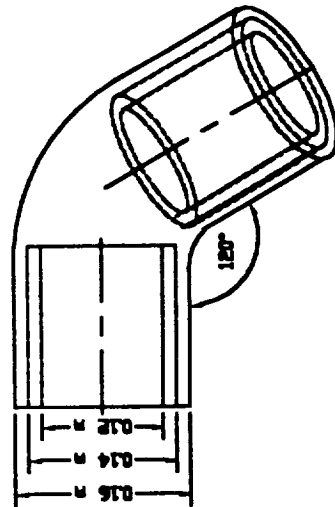
Date: 11/23/93 Scale: None

Note: Δ ASTM Internal Double Thread (9 on pitch, 100 thread per inch)



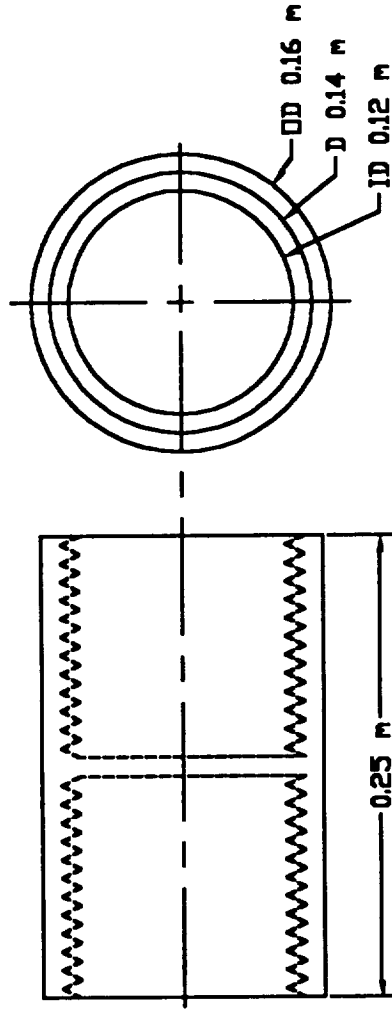
Notes:
 ⚠️ ASTM Internal Double Thread (.9 cm pitch, 100 thread per meter)
 ⚠️ ASTM Internal Double Thread (.45 cm pitch, 50 thread per meter)

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Part Name: Base Conn.
Date: 11/23/93 Scale: None



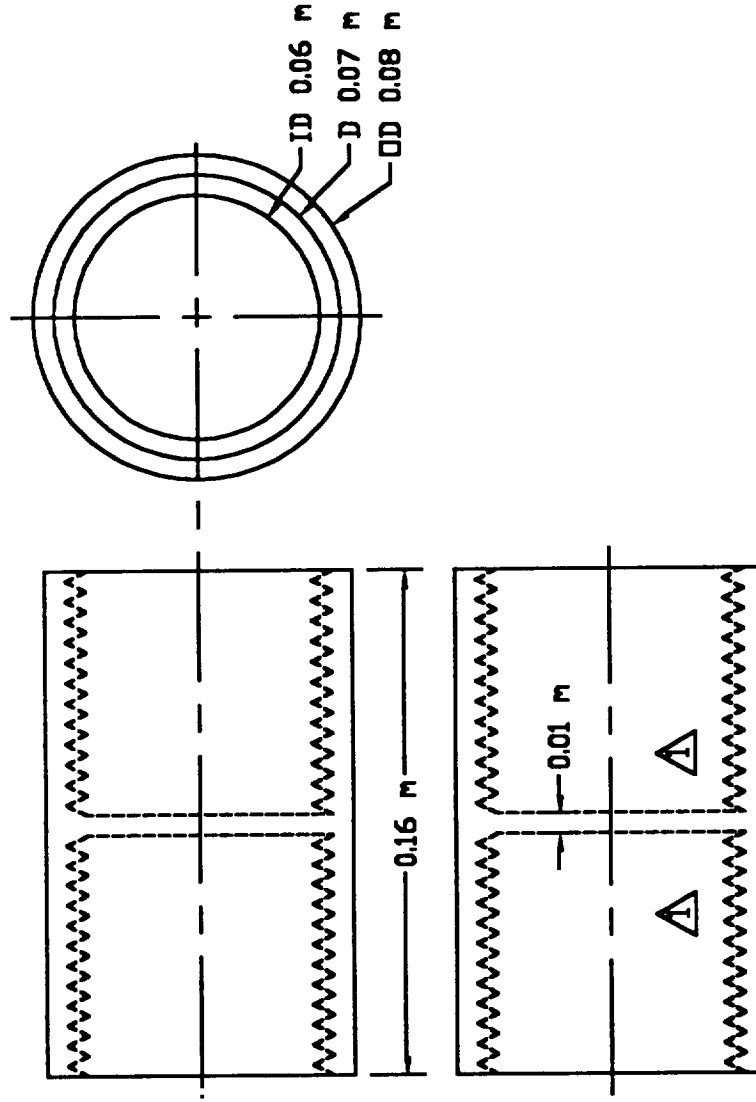
Note: Δ ASTM Internal Double Thread (9 on pitch, 100 thread per meter)
Three connectors at 60 degrees from each other

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Date: 11/23/93 Scale: None



ME4182 - M.E.T.S. Design
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Part Name: Primary Conn.
Date: 11/23/93 Scale: None

Note: Δ ASTM Internal Double Thread (9 cm pitch, 100 thread per meter)

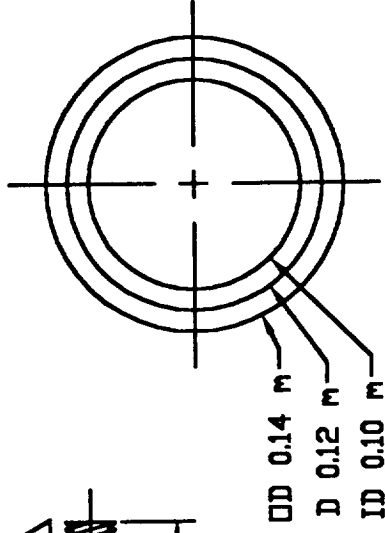
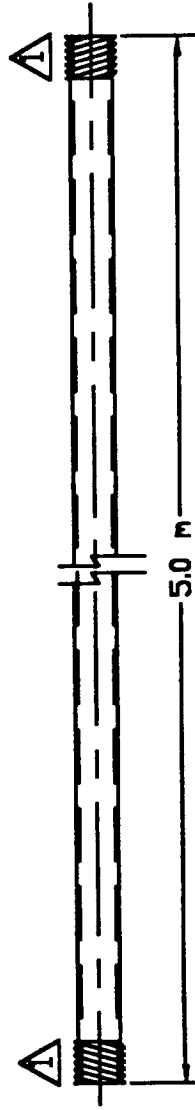


ME4182 - M.E.T.S. Design

Material - Graphite/Epoxy

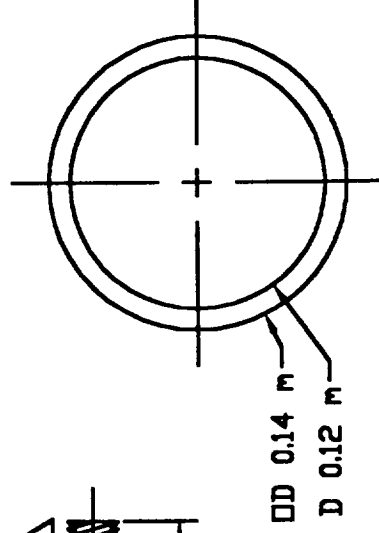
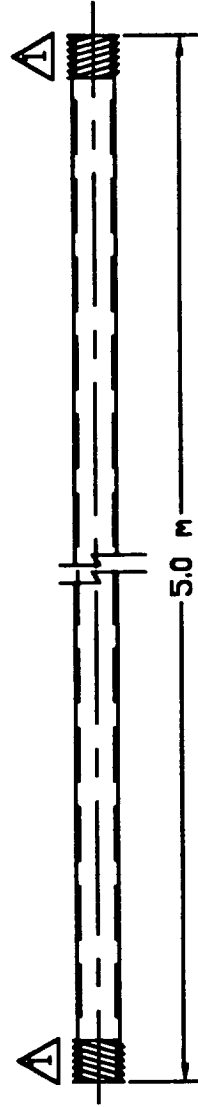
Part Name: Secondary Conn.

Date: 11/23/93 Scale: None



Note: Δ ASTM External Double Thread (9 cm Pitch, 100 thread per meter)

ME4182 - M.E.T.S. Design
Material - Graphite/Epoxy
Part Name: Primary Leg
Date: 11/23/93 Scale: None



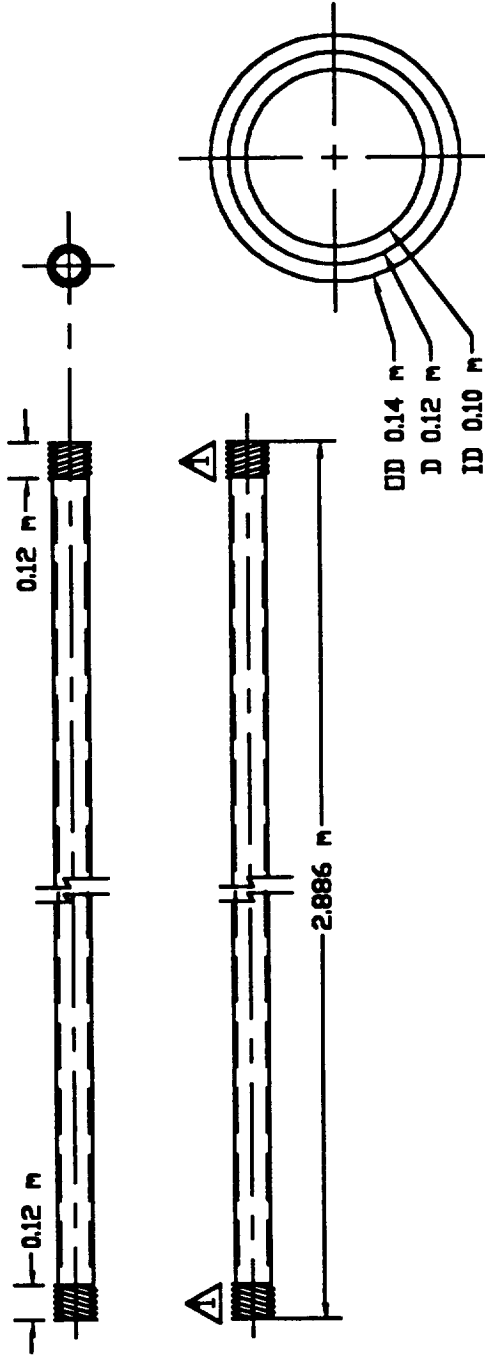
Note: Δ ASTM External Double Thread (9 cm Pitch, 100 thread per meter)

ME4182 - M.E.T.S. Design

Material - Graphite/Epoxy

Part Name: Delta Leg

Date: 11/23/93 Scale: None



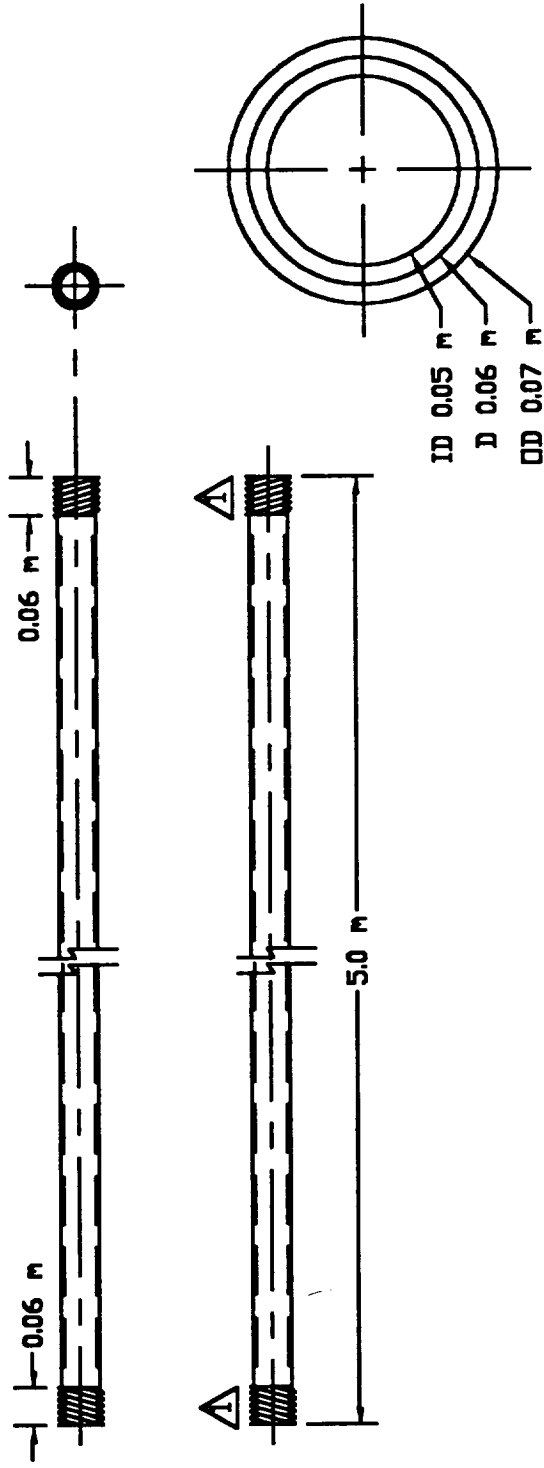
Note: Δ ASTM External Double Thread (9 cm Pitch, 100 thread per meter)

ME4182 - M.E.T.S. Design

Material - Graphite/Epoxy

Part Name: Apex Leg

Date: 11/23/93 Scale: None



Note: Δ ASTM External Double Thread (45 cm Pitch, 50 thread per meter)

ME4182 - M.E.T.S. Design

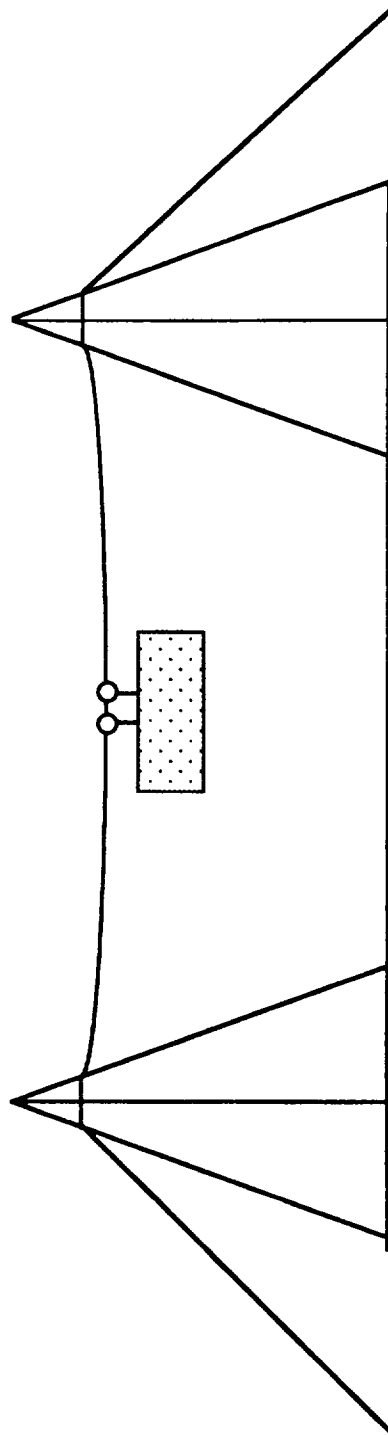
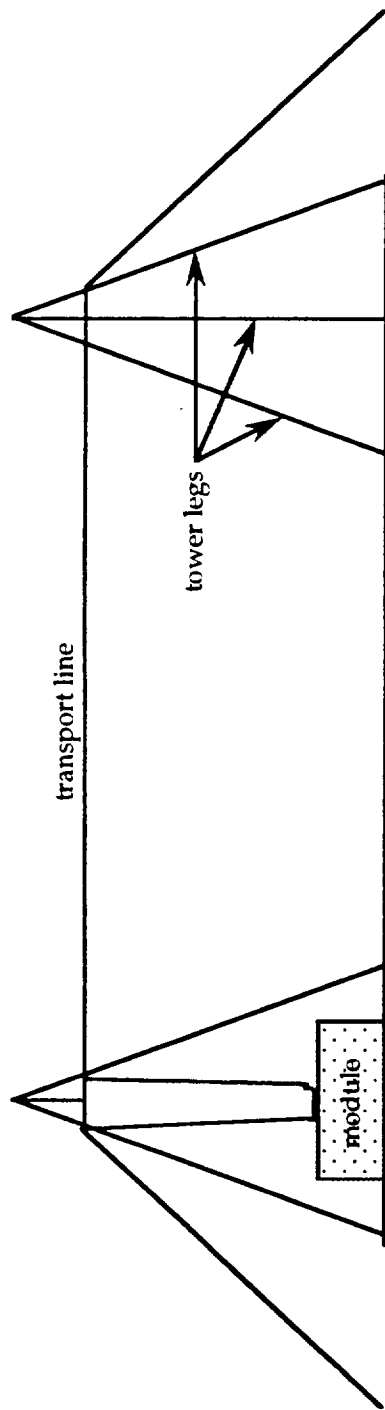
Material - Graphite/Epoxy

Part Name: Base Leg

Date: 11/23/93

Scale: None

HORIZONTAL TRANSPORT



XI. REFERENCES

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XII. GROUP NOTEBOOK APPENDIX

Appendix A.	Kevlar rope
Appendix B.	Pulley systems
Appendix C.	Composite component selection
Appendix D.	Methods of anchoring
Appendix E.	Hydraulic Winches
Appendix F.	Research of concept